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W. H. Bellew.

1900

THE

ECONOMIC THEORY

OF THE

LOCATION OF RAILWAYS.

ROBERT DRUMMOND, ELECTROTYPER AND PRINTER, NEW YORK.

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ECONOMIC THEORY

OF THE

LOCATION OF RAILWAYS

AN ANALYSIS OF THE CONDITIONS CONTROLLING THE LAYING OUT OF RAILWAYS TO EFFECT THE MOST JUDICIOUS EXPENDITURE OF CAPITAL

BY

ARTHUR MELLEN WELLINGTON

M. AM. SOC. C.E.; M. INST. C.E.

LATE PRINCIPAL ASSISTANT ENGINEER FOR LOCATION AND SURVEYS MEXICAN NATIONAL RAILWAY, ASSISTANT GENERAL MANAGER IN CHARGE OF LOCATION MEXICAN CENTRAL RAILWAY AND CHIEF ENGINEER OF THE AMERICAN LINE FROM VERA CRUZ TO THE CITY OF MEXICO

"For it is clear that in whatever it is our duty to act, those matters also it is our duty to study."

—DR. THOMAS ARNOLD

SIXTH EDITION, CORRECTED

FIRST THOUSAND

NEW YORK

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The writer does not intend to imply, however, that he has fallen into unacknowledged errors of fact or theory. All known errors have been frankly corrected as soon as discovered. For such others as may probably exist the writer can only hope that they will be regarded with that leniency which an exploration of a neglected field of labor may fairly ask. For such the present volume is, with all its imperfections. A recognition of the value of previous discussions of the same subjects would be a more welcome duty; but the writer deems it but simple justice to himself and his readers to declare frankly that, so far as his knowledge extends and he is competent to judge, all of the few existing discussions of the various leading topics of this volume are so superficial or so imperfect in method as to have little or no value as a guide for location. Some of them express correct views, and some of them will sometimes give correct results; but none of them are *trustworthy*, and several of those which are given under distinguished names are incredibly defective. The various problems of location, in fact, have been dis-

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ONLY in a very figurative sense can this book be said to be a "revised edition" of the little volume under the same title which the writer published ten years ago. The substance of the old book remains unchanged, so far as it went, but every page and sentence has been rewritten, except the dedication. The most important change in the nature of an addition is the much greater attention given to traffic and revenue questions, which are particularly likely to be underrated or forgotten. The mechanics of curve resistance have been discussed, it is hoped, more adequately than heretofore, and on a more solid basis of experimental fact, with some important practical questions which depend thereon. The theory of the effect of variations in velocity on the motion of trains is an entirely new addition, supplying one of the most important omissions of the former edition and of other engineering text-books. The theory of various details of the locomotive, which did not seem to have been elsewhere adequately discussed for the purposes of this volume, has been given, it is hoped, more fully and correctly than heretofore. Parts IV. and V. are entirely new.

On the other hand, the new edition has been abbreviated by omitting the discussions, some thirty in all, where reasons why the writer felt compelled to differ from some previously published conclusions or estimates were given in detail. This seemed necessary ten years ago, but at present it appeared as if the space might be better used.

The number of engravings has been increased from half a dozen to 313, the number of pages from 216 to 950, and the number of tables from 44 to 204. All of the tables, with a few exceptions noted in connection with each, are original computations of the writer or compilations from original sources of information. As practically all the work of preparing them, and of rewriting the text, has been done outside of those hours which are ordinarily and more rationally regarded as working hours, a long delay in republication has been unavoidable; but if there be truth

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enough in the old antithesis of "easy writing" and "curst hard reading" to hold good when twisted wrong end to, there should be some compensation in store for any reader who may have chanced to be annoyed by the delay.

In order to adapt the volume to the more convenient use of all classes of readers, three sizes of type have been used:

LONG PRIMER type is used for those parts of the volume which were deemed most likely to be such as every interested reader would wish to read, including those who desire only to ascertain the more important conclusions, free from technicalities.

BOURGEOIS type is used for discussions which relate more to the details of the subject than to principles, and hence may be passed over by those who are not engineers, or who are ready to take the reasons for what is printed in larger type for granted. Nevertheless, much of the matter which is printed in this smaller type, as for instance the long chapter on the locomotive engine and the whole of Part V., is among the most important in the book for the professional engineer.

BREVIER type is used for minor notes and comments which it seemed essential or desirable to give, as of much possible importance to those wishing to look into the subject, or some particular branch thereof, with still greater care, but which might otherwise be passed over.

The mathematical form of discussion has been intentionally avoided, first, because the book has been written for practical men as well as for students, and mathematical methods are apt to repel them; and secondly, and chiefly, because mathematical methods of solution are not only inexpedient, but positively dangerous for the class of problems considered. When the difficulty of a problem lies only in finding out what follows from certain fixed premises, mathematical methods furnish invaluable wings for flying over intermediate obstructions; but whenever the chief difficulty of a problem lies in the multiplicity and dubiousness of the premises themselves, and in reconciling them with each other, there is no safe course but to remain continuously on the solid ground of concrete fact. The invidious but simple task of proving this by instances the writer will not attempt.

To fully set forth in any one volume these premises for the correct laying out of railways, which include almost everything connected with their construction, operation, and finances, and vary in each case, would

be impossible. The purpose in view has been merely to give between the covers of one book whatever was necessary for some approach to a correct solution of every probable problem, which could not be found in other publications. This necessarily led to a large book, since this work still remains the only one on its subject in the language. Several of a somewhat similar nature have appeared in French and German since the first edition of this work was published, but from difference of operating conditions, and their profuse use of mathematics, the resemblance is not close.

The word "ton" in this volume means 2000 lbs., unless otherwise explicitly stated.

The term "velocity-head" has been borrowed from hydraulics to designate a somewhat different thing, which heretofore has had no name at all. The "velocity-head" of hydraulics and of this volume are closely related but not identical, and should not be confused.

Grades have been designated for the most part by their rate per cent and not by their rate per mile, in accordance with an increasing custom which may well become universal, as the more rational. The approximate rate per mile is given at once by multiplying the per cent by 50 (52.8).

Owing to the great number of tables, and the probability that others might be added in future editions, it was impossible to even attempt to refer in the text to all those which contained a given class of information. To insure doing this reference must be had to the Index, which it has been endeavored to make very complete.

Most of the computations of percentages, costs per mile, and the like, in this volume, were made with a slide-rule—an instrument too little known and used by engineers. Hence many errors of 1 or 2 in the third digit, or of one or two tenths of one per cent, probably exist, but, it is hoped, few of a more serious nature. The admirable computing instrument of Mr. EDWIN THACHER, which would have insured greater accuracy with but little more trouble, was secured by the writer too late to be of much service.

The author will be at all times pleased to receive corrections of typographical or other errors, or supposed errors, extensions of any of the tables, or other similar matter.

A. M. W.

TRIBUNE BUILDING, NEW YORK, May, 1887.

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PART III.

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PART IV.

LARGER ECONOMIC PROBLEMS.

PART V.

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INDEX

TO THE MORE IMPORTANT

RULES, TABLES, FORMULÆ, AND FINAL CONCLUSIONS,

WHICH MAY BE NEEDED

FOR IMMEDIATE APPLICATION.

"It may be remarked that it was no part of the purpose of this volume to furnish a collection of mere rules, professing to require only an ability to read for their successful application. Rules can seldom be safely applied without a clear understanding of the principles on which they rest."

—J. B. HENCK, Preface to "Field-Book."

[*This index has purposely been made and kept as brief as possible.* IT HAS NO CROSS-REFERENCES NOR DOUBLE REFERENCES. *For anything not found, see General Index, where the subjoined references are repeated, and for the most part in* SMALL CAPITALS.]

THE ECONOMIC THEORY OF THE LOCATION OF RAILWAYS.

INTRODUCTION.

As the correct solution of any problem depends primarily on a true understanding of what the problem really is, and wherein lies its difficulty, we may profitably pause upon the threshold of our subject to consider first, in a more general way, its real nature; the causes which impede sound practice; the conditions on which success or failure depends; the directions in which error is most to be feared. Thus we shall more fully attain that great prerequisite for success in any work—a clear mental perspective, saving us from confusing the obvious with the important, and the obscure and remote with the unimportant.

It would be well if engineering were less generally thought of, and even defined, as the art of constructing. In a certain important sense it is rather the art of not constructing; or, to define it rudely but not inaptly, it is the art of doing that well with one dollar, which any bungler can do with two after a fashion.

There are, indeed, certain great triumphs of engineering genius—the locomotive, the truss bridge, the steel rail—which so rude a definition does not cover, for the bungler cannot attempt them at all; but such are rather invention than engineering proper. There is also in some branches of engineering, as in

bridge-building, a certain other side to it, not covered by such a definition, which consists in doing that safely, at some cost or other, which the bungler is likely to try to do and fail. He therefore, in such branches, who is simply able to design a structure which will not fall down, may doubtless in some measure be called an engineer, although certainly not one of a very high type.

But to such engineering as is needed for laying out railways, at least, the definition given is literally applicable, for the economic problem is all there is to it. The ill-designed bridge breaks down; the ill-designed dam gives way; the ill-designed boiler explodes; the badly built tunnel caves in, and the bungler's bungling is betrayed. But a little practice and a little study of field geometry will enable any one of ordinary intelligence, without any engineering knowledge whatever in the larger sense, to lay out a railway from almost anywhere to anywhere, which will carry the locomotive with perfect safety, and perhaps show no obtrusive defects under what is too often the only test—inspection after construction from the rear end of a palace-car. Thus, for such work, the healthful checks which reveal the bungler's errors to the world and to himself do not exist. Nature, unhappily, has provided no way for the locomotive—like Mr. Jingle's intelligent pointer—to refuse to pass over an ill-designed railway as it refuses to pass over an ill-designed bridge.

Therefore, since there is no natural line between safety and danger to mark even so rude a distinction as that between the utterly bad and the barely tolerable, in the kind of engineering work we are to study, one may fairly say that the locating engineer has but the one end before him to justify his existence as such—to get the most value for a dollar which nature permits; and but one failure to fear—that he will not do so. Except as his work necessarily involves the preliminary design of constructive details, he has no lives to save or imperil; and the young engineer cannot too early nor too forcibly have it impressed upon his mind that it takes no skill worth speaking of to do such work after a fashion, unless in the comparatively few localities (rare in-

deed in the United States) where to get a reasonable line of any kind is something of a feat. His true function and excuse for being as an engineer, as distinguished from a skilled workman, begins and ends in comprehending and striking a just balance between topographical possibilities, first cost, and future revenue and operating expenses.

While this, in a certain sense, is peculiar to the branch of engineering we are to study, yet a curiously close analogy may be drawn, tending to show that it is as essentially true of all other branches of engineering as of this. For example, it is beyond doubt that the true reason for the striking progress in bridge-building in recent years has been, not that men have been driven into excellence by "the responsibility of human life" resting on them ;—for, after the types have once been invented, a relatively low order of engineering skill suffices to reduce that risk alone to a minimum. But the impelling force has been the keen competitive struggle to bring the first cost of every bridge as low as possible, and yet do nothing which shall injure its permanent efficiency and compel it to be speedily rebuilt ; nothing, in other words, which shall increase the future "maintenance and operating expenses." But whereas the "operating expenses" of bad bridge-engineering come in a series of startling catastrophes which shock the community and dismay the moneyed interests concerned, causing good work to be appreciated and insisted on, and scaring off the amateurs and 'prentice hands from "meddling and muddling," after the manner of their kind, the operating expenses from bad railway location come by a gentle but unceasing ooze from every pore which attracts no attention, albeit resulting in a loss vastly larger than any possible loss from bad construction ; for it requires some training and experience even to appreciate the loss as existing, and still more of both to appreciate it as remediable. In fact no one can do so, except in the most general way, without special investigation of each special case. Errors which, even if committed, are not likely to be discovered, are rarely much feared, and at last the consciousness that there is danger of error becomes dulled.

In these facts we have plain reasons why average practice in laying out railways should inevitably tend, as it does tend, to be and remain of a low grade. It is not difficult, in fact, to see reasons why it can never well be otherwise, except in degree, unless the progress of science should wholly change the nature of the work; and a correct appreciation of how great is this danger, and why it exists, will greatly help to save the student from it.

The permanent difficulty lies in this: High efficiency in any art or calling in which many minds of no phenomenal gifts are engaged requires that every man's work should be readily comparable either with a certain uniform standard or with the work of his fellows. In constructive engineering this is possible. Broadly speaking, a hundred-foot bridge is a hundred-foot bridge, the world over. It has everywhere to fulfil but two primary conditions: It must carry a certain nearly uniform load per foot, and it must not fall down. The same is in substance true of every form of constructive engineering. Every man's practice therein, therefore, is comparable, and is compared, with the highest level of practice, the world over. Those most highly skilled are discovered and recognized. The moderately skilled perceive and correct their deficiencies. The hopelessly unskilled retire to other pursuits.

In laying out railway lines, and less strikingly in some other analogous kinds of engineering work, this is forever impossible. We cannot reduce the laws of topography, nor even of finance, to equations and formulæ. Every line is a problem by itself, with its own peculiar physical and commercial conditions, so that the engineer is deprived of the aid to be had by comparing with, and copying the details of, the practice of others. Under these circumstances, the difference of conditions will be apt to be honestly accepted by the reader who may have sinned against good practice, and by all others concerned, as the reasons why another line, one hundred or one thousand miles off, should have cost so much less and yet be so much better worth owning than his own. He who has done well, therefore, is cut off from any

absolute knowledge and general recognition of that fact, and the guilty reader, who has done ill, is cut off from the still greater gain which would come to him from a revelation of where and wherein he has done ill. In most such cases each will have in some detail shown better judgment than the other; but from the lack of unquestionable evidence of this, each is denied the instruction which he might otherwise receive from that fact, and so is in great danger of falling into the most natural and most human error, believing that all that he has done is good, which has not been proven to be bad, and so ceasing to make effort to improve upon what is good enough to pass, and merely multiplying errors with advancing experience, without really advancing in knowledge.

For these reasons the student should begin with the consciousness that the level of average practice in railway location, his own included, is by its nature restricted, not to the sum of the united abilities of all those who are or have been engaged in it, as in constructive engineering, but to the average individual level of capacity and knowledge. No more is needed than this undoubted fact to prove to demonstration that average practice is and must be, both comparatively and absolutely, of a pretty low grade; and hence it becomes every one who may be entrusted with such work to have constantly before him the fact that he stands thus alone, and to scrutinize with the sternest skepticism, the conclusions which he may reach, remembering that his danger of grave errors of judgment is thereby multiplied manyfold. As he measures only by his own knowledge, all the work he does will naturally seem good even if really bad.

To the preceding, which may be called the subjective obstacles to good practice, must be added another and perhaps a greater one. Inasmuch as no one can even know for himself the absolute quality of his own skill in this particular branch of engineering, it is almost a natural corollary that corporations should very uniformly decline to take it for granted, by assuming that there are any measurable differences in qualifications for such work among those who have proved their competency in

other branches of engineering. Hence it happens that railway location tends more and more to be entrusted to those to whom it is a mere temporary incident in their professional career, and who consider the work mainly from the constructive standpoint, without much attention to those larger economic questions which it is the purpose of this volume to discuss, and to which, in well-conducted work, the mere constructive details should be wholly subordinate. But as the inexperienced young man can only gauge the importance of various work by the attention which he sees paid to it by his superiors, he is, as it were, pushed by others into an error which it is difficult for him to avoid at best ; for he will soon note that the assumption and practice of the world is, that whoever is fit to design the structures of a railway is thereby fitted, without further study or preparation, to design the railway as a whole. In fact, this vicious principle is in very many instances pushed to the absurd extreme of entrusting engineers of inferior capacity with the location of railways, and only seeking for a higher grade of skill when the design of the cheaper man is to be embodied in construction. The error in so doing is the same in kind and in degree as if it were assumed that whoever was fitted to build a house was fitted to design one. The mental qualities and special training needed are much the same in each case, but the two kinds of work are distinct, and skill in one does not argue skill in the other.

Nevertheless, railways must be built, and fortunately there is a bright side as well as a dark side to the picture. There is indeed a pitiable waste resulting from the conditions outlined : such, to mention a simple and readily comprehended example, as has resulted from the location of the entire railway system of the prairie States of the West,—taking it as a whole and neglecting the many individual exceptions,—where the fatal ease with which an air-line may be run from almost anywhere to anywhere, by using heavy enough grades, has brought the average train-load lower than in the rugged regions of the East, and caused perhaps a greater percentage of utterly needless waste,

and a more discreditable aggregate of thoroughly bad location, than in any other considerable region of the world ; and in view of such facts, the distorted pre-eminence given by engineers, and by those who teach them and employ them, to the pettiest details of *how* to build the separate works which make a railway, to the neglect of the larger questions of where to build and when to build, and whether to build them at all, has in it something at once astounding and discouraging. But in a larger view this is in no way surprising. It is but the common result of man's attempts at solving every serious problem which does not admit of exact and positive solution, like a problem in geometry, but contains such indeterminate elements that to solve it perfectly is given only to Omniscience. In all such cases mankind in general shirks the issue, or jumps at a solution in the rudest way, as is seen not only in the work of engineers, but in that of farmers and legislators and merchants, physicians and builders. Compared with the dismal failure which so many men make in every one of these callings, the work of engineers in laying out railways shines by comparison. For after all, the fact, if it be a fact,—as in a rude way it is,—that between waste in construction and waste in operation and waste from inaccessibility to possible patrons, it takes about twice as great expenditure of capital and labor as it need to afford existing transportation facilities—this really means no more than that, instead of realizing ninety per cent of the advantages which might be gotten from George Stephenson's invention, as is reasonably possible, only some seventy-five or eighty per cent is actually realized. The great world declines to take much interest in such a trifling waste as this, being accustomed to much greater waste in many things, and having something of that large indifference to waste which pervades all nature. Nor would it be worth while here to insist on it for the mere sake of pointing out that it exists, but solely to point out that, as the location of railways is the one department of engineering in which waste on a gigantic scale is possible from probable errors of judgment, and as it is likewise the one department of engi-

neering in which no natural check exists against such errors, it is fitting that engineers should prepare themselves for it with especial care, at least to the extent of acquiring an adequate conception of the number and magnitude of the errors into which they may fall.

Much of the success of any one in any kind of work, and especially in work subject to the peculiar difficulties of that we are considering, depends upon the spirit in which it is undertaken. If it be true, as it unquestionably is, that no one ever attained great success in any walk of life—or certainly in no intellectual calling—who found no other nor higher pleasure in doing that well which was given him to do than in the money or the glory which he might get from doing it, it is certainly much more true in a calling where those ordinary stimuli work very imperfectly or not at all, and in which one is often called upon to do the direct contrary of what will win him credit from the thoughtless and superficial. The desire to do good work for its own sake is then the only real guarantee that good work will be done; for although a kindly Providence has given the latent power to do bad work of this kind to every human being with a tolerably observant eye and intelligence enough to lay up bricks, most assuredly the power to do good work will not come by nature. The author, therefore, feels that he need make no apology to those young men who may honor him by studying this volume, for offering them one page at least of true wisdom, in the stately periods of one of the greatest thinkers of our or any age; which he does in the belief that they will find its study more profitable than that of many pages in this or any other text-book, since, if they have studied it to some purpose, they are at least assured the most permanently gratifying of all success—the consciousness of having done one's best:

"I look on that man as happy, who, when there is question of success, looks into his work for a reply—not into the market, not into opinion, not into patronage. In every variety of human employment, in the mechanical and in the fine arts, in navigation, in farming, in legislating, there are among the numbers who do their work perfunctorily, as we say, or just to pass, and as badly as they dare,—there are the workingmen, on whom the burden of the business falls,—those who love work, and love to see it rightly done, who finish their task for its own sake; and the state and the world is happy that has the most of such finishers. The world will always do justice at last to such finishers: it cannot otherwise. He who has acquired the ability may wait securely

the occasion of making it felt and appreciated, and know that it will not loiter. Men talk as if victory were something fortunate. Work is victory. Wherever work is done, victory is obtained. There is no chance, and no blanks. You want but one verdict: if you have your own, you are secure of the rest. And yet, if witnesses are wanted, witnesses are near. There was never a man born so wise or good, but one or more companions came into the world with him, who delight in his faculty and report it. I cannot see without awe, that no man thinks alone, and no man acts alone; but the divine assessors who come up with him into life, now under one disguise, now under another, like a police in citizens' clothes, walk with him, step for step, through the kingdom of time.

"What is vulgar, and the essence of all vulgarity, but the avarice of reward? 'Tis the difference of artisan and artist, of talent and genius, of sinner and saint. The man whose eyes are nailed, not on the nature of his act, but on the wages,—whether it be money, or office, or fame,—is almost equally low." *

The true moral to be drawn from such glittering generalities is not that if a man does not succeed the world is not doing justice to him; for the chances are a hundred to one that it is meting him out exact and equal justice, and that unless he wipes out that delusion from his mind and sets about correcting his deficiencies, it will continue to do so in the same way: nor is it that a man should neglect that reasonable care for his own welfare which is every man's duty, nor that he should submit to imposition, nor continue very often, for very long, to render something for nothing: In this utilitarian age there is little danger that it will be so interpreted. But the author has seen—or thinks he has seen—so many young men doing permanent injury to their own future by letting $150 a month fill up the whole arc of their horizon, that he has seized his chance, while he has them foul, to inflict a little advice. He grants it is against the laws of the game, and stops.

We will now proceed with our legitimate subject, and endeavor not to depart from it.

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* **Ralph Waldo Emerson: "Essay on Worship."**

PART I.

ECONOMIC PREMISES.

"The location of a railroad is giving it its constitution. It may be sick, almost unto death, with accidents of construction and management, but with a good constitution it will ultimately recover."

—D. H. AINSWORTH.

PART I.

ECONOMIC PREMISES.

CHAPTER I.

THE INCEPTION OF RAILWAY PROJECTS, AND CONDITIONS GOVERNING IT.

1. WHEN a railway is projected, and while its construction is still in doubt, the most important and most doubtful question of all is one which does not admit of any general discussion or analysis : WHETHER OR NOT TO BUILD THE LINE AT ALL. The decision of this question is not within the legitimate sphere of an engineer's duties, acting as such ; and hence it should not be permitted to confuse or affect his mind during the subsequent process of preparing the line for construction. For the general question of whether or not to build the line at all is one of finance and business judgment alone, to be settled by a more or less exact or visionary estimate of the available capital for construction, the probable gross and net receipts, and the resulting direct and indirect advantages to the projectors, with the final conclusion that—

(1) There is (or is not) sufficient need of a railway to give a fair return on the expenditure of a certain gross amount in constructing it; and

(2) That this gross amount can (or cannot) be raised.

This conclusion is not necessarily expressed by a definite sum in advance—in fact it is very rarely so expressed ; but such a

conclusion is in effect reached, although often in a very vague form, whenever it is decided to proceed with construction.

2. Neither does it follow that the deciding motive is direct pecuniary profit; for the line may be of great value to the investors and the public, and yet never pay such profit. In fact, the railway system of the world, taken as a whole, and especially that of the United States, has been only very moderately profitable in any direct form; owing not so much to mistakes of judgment pure and simple, as to the very large proportion of lines which have been built simply to increase the value of land, to afford local transportation facilities, to bring traffic to the main line, and similar purposes. Yet the resulting gain to the community, from these indirect advantages alone, has been vast beyond computation; so much so that, although the lines on which projectors have lost money have been many, there have been few or none which have involved a positive loss to the community as a whole, excepting some of those which have merely paralleled other lines.

3. A certain number of lines, also, are built for more or less illegitimate and irregular purposes: to sell out to, or sometimes, one may fairly say, to black-mail other lines; to make profit on the construction; as means of warfare against other lines; etc., etc. Nevertheless, even with such irregular enterprises, as certainly in all other cases, the same general law holds: It is the plain interest of the constructors, in all cases, to obtain as good a road as they can for the money, and to build it on business principles; to spend what they have to spend to the very best advantage, and to spend no more than they are obliged to spend to build the line at all in safe operating condition, unless the additional expenditure, and not simply the expenditure as a whole, is clearly a good investment.

4. From the point of view of this volume, therefore, all railways are legitimate enterprises, and their construction is governed by the same general economic laws. These laws, vital to the successful conduct and outcome of such enterprises, seemingly very plain and simple, but frequently neglected or forgot-

ten, may, as respects the question of whether to build the line or not, be summarized as follows :

5. (1) Railways are not undertaken unless they are expected to be profitable, not to the general public, nor to other parties in the near or distant future, nor to those who lend money on them, *but to those who at first control the enterprise.* If the means in hand be not sufficient for the projectors to complete the road for operation and to control its operation afterwards, the result to them is usually complete loss. Remembrance of this fact becomes the more important because the available means (the great bulk of which is borrowed money) are almost always overrated, and the demand upon them underrated.

The logical order of procedure in the case of any new enterprise—which is, first, to determine whether or not the project is a sound one, and to be carried out ; and, secondly, to make the necessary studies as to the manner of carrying it out—is not necessarily followed in order of time : often it cannot be, for the final decision as to the former often depends on the results of the latter, or on unknown future events. Nevertheless, although subsequent events may cause a revision of such assumptions, the mere initiation of the study of details implies a *pro-forma* conclusion, that the project as a whole is a wise one if wisely carried out, and can only fail by bad judgment in details. This premise must be from the beginning, therefore, under all circumstances, the basis of the engineer's action. From this it follows :

6. (2) No increase of expenditure over the unavoidable minimum is expedient or justifiable, however great the probable profits and value of an enterprise as a whole, unless the INCREASE can with reasonable certainty be counted on to be, in itself, a profitable investment. Conversely,

(3) No saving of expenditure is expedient or justifiable, however doubtful the future of the enterprise as a whole, when it can with certainty be counted on that the additional expenditure at least will, at the cost for the capital to make it, be in itself a paying investment.

For if the project as a whole be an unwise one, the projec-

tors will lose their money in any case; but an additional expenditure which adds more value to the property than it costs will, at the worst, decrease their loss, and may turn the scale by preventing any loss. Doubtful projects least of all can afford to have their future imperilled by reckless economies. Nevertheless the following should be remembered:

7. (4) No expenditure is wise, however otherwise profitable, which endangers the successful completion of the enterprise with the funds on hand or known to be available.

For the property then becomes worthless to the projectors, however valuable it may become to others. Successful completion, moreover, includes much more than the laying of the track. It includes the equipment, the terminal facilities, the endurance of thin traffic and of imperfect exchange-traffic facilities until the normal business of the line has been fully attained—always a matter of time. Therefore, as few roads are even sure of obtaining the capital which they think is necessary for the above purpose, we have the following:

8. (5) Expenditures of any kind on new projects are rarely wise, however otherwise profitable, which can be postponed without any very serious loss, however sure to involve some loss if all goes as well as is expected;—such as costly works which can be avoided by temporary lines, or by less durable but cheaper structures, complete provisions for traffic which is yet in the future, and elaborate shops and buildings.

On the other hand, economies which permanently handicap the line with inferior works or alignment, or which place it under a permanent disadvantage in seeking for business, such as using over-light rails, keeping away from towns to save right-of-way expenses, heavy grades, etc., are the first which should be avoided, but are often the first which are resorted to, for reasons more fully discussed in Chapters XXII. and XXIII.

9. The profit on a railway property depends, *first*, on the judgment shown in selecting the region through which it is to be built; and, *secondly*, on the skill with which the line laid down in it is adapted to be of the greatest use to the greatest number

of people (giving large gross revenue) at the smallest cost for the service rendered (giving small operating expenses). The first is distinctively the province of the projectors; the last is distinctively the province of the engineer. Which is most important it would be needless to inquire, but certainly the last, in this sense at least, that, if it be well done, any errors in respect to the assumed need for a railway, although they may be unfortunate, can rarely be ruinous; while it has again and again been proven that if good judgment be not shown in the details of the route and expenditure, no merely constructive skill of the engineer, nor excellence of judgment in selecting a locality, can save the project from disaster.

10. All the preliminary questions of probable profit and loss involved in the decision to build a line of some kind over some given general route being supposed to be finally settled and disposed of, and the construction of the road definitely determined on (if the expectations as to cost of construction and available means are realized), the province of the locating engineer and the proper subject-matter of this volume begins.

We are now done altogether with all considerations as to whether the future of the company as a whole will be prosperous or otherwise, and as to whether the probable aggregate profits or cost of the road, either per mile or in gross, will be large or small, and it is the duty of the engineer to neglect them absolutely in laying out his work, considering only the effect of his decisions upon these three items:

1. THE DIFFERENCE in gross receipts which will or may result from choosing one or another line.

2. THE DIFFERENCE in operating expenses which will or may result from choosing one or another line, one or another gradient, one or another limit of curvature, etc.

3 THE DIFFERENCE in annual interest charge which will or may result from the differences in cost of construction caused by differences in the above details.

The latter should be computed, of course, at the rate or rates

of interest which money actually costs or will cost his company. This is supposed to be known to, and remembered by, the engineer; and is the only fact connected with the present condition or future prospects of the finances of his company which should legitimately influence his decisions.

11. Not unfrequently this rate of interest cannot be considered uniform, but must be assumed to increase very rapidly with the amount invested; and not unfrequently the rate of interest which should properly be assumed will verge upon the infinite. It is always more likely to be underrated than overrated; whereas prudence requires that the reverse should be the case.

But however great or small the amount and cost of the available capital, although our decisions themselves will vary, yet the methods by which these decisions are reached will not vary; for even in such an extreme case as when the cost of more capital than is absolutely essential is infinitely great, we are simply permanently reduced to, and compelled never to vary from, what should be the *à priori* basis for construction with which the construction of every line is entered upon,—however prosperous the company, however large the probable traffic and profits,—because no more than this is implied in the mere decision to build the road, which is:

That excepting when and as specific reasons to the contrary appear, the cheapest line is to be built over which it is physically possible to carry the probable traffic with proper safety and speed, using to this end any grades and curves and length of line which may be most conducive to this end only—and never abandoning it by increasing the expenditure, unless the investment—not the investment as a whole, for the line as a whole, but *each particular investment for each particular purpose at each particular point—will be in one way or another profitable in itself.*

12. In other words, reduction of first cost to the lowest possible point is, in logical or economic order, the first consideration; although therefore not by any means either the most important or the governing consideration. That this is so is easily seen, however often forgotten. It is not only business-like

common-sense for the investors and their servants, but it is sound political economy for the community as a whole. It does not mean nor imply cheap and shabby construction. It simply means AN AVOIDANCE OF WASTE, either in saving money or spending it. It simply means a recognition of the fact that every dollar and every day's work which goes into the ground and does not bring something out of it, makes not only the individual but the whole community the poorer. The welfare of all mankind, as well as of investors in the enterprises which employ engineers, depends upon the skill with which the investment in its constructive or manufacturing enterprises (destruction of existing capital) is kept small, and the productive or earning power (creation of new capital) is made large. The difference between the two is the so-called "profit" (net addition to existing capital), which goes indeed into the control of those who created it by perceiving the (supposed) opportunity or necessity and using their own means at their own risk to supply it; but it is not, therefore, for the true interest of any person or class to make it less by increasing the investment, for otherwise there is a waste which, as it benefits no one, indirectly injures all. Not even the laborer who uses up a portion of the wasted capital is really the gainer; for if, on the one hand, the capital spent (*i.e.*, destroyed) for construction or plant be needlessly large, although the poor man gains, for the time being, wages which he would not otherwise receive from that particular enterprise, yet it is as if he were paid wages to turn a crank which ground no grist—his time and his work go for naught. If he spend half his time in this way he must, in the long-run, do two days' work for the wages of one—a condition which is nearer to existing in railway enterprises than is always realized or admitted.

Comparison of the condition of laborers in countries and ages where human labor is economized (reduced to a minimum for each separate service) and where it is not, fully establishes this important economic truth, as to which many false notions prevail.

13. On the other hand, if the proper margin of profit has been reduced by reckless and costly economies, no one gains

even the semblance of benefit, while both the projectors and the patrons of the enterprise are heavy losers—the projectors in money, the patrons in convenient service.

These two vital truths, therefore, which directly result from what has preceded, should never be forgotten: that because a line will have or is expected to have a prosperous future—because, perhaps, it is to be built by the State for great reasons of state, or for any other reason will have plenty of money in the treasury, there is therefore no justification in that fact alone for making it a costly road as well.

On the other hand, no road is so poor that it can afford to economize when certain additional expenditure will be clearly very profitable. If it is clearly understood, or believed for good reason, that a given additional investment will certainly pay 10 or 15 or 25 or 50 per cent, as the case may be, it may almost be said that the poorest company can find ways and means for obtaining the capital, if the facts be properly and clearly presented.

14. The temptation to err by neglecting these axiomatic laws—which is always present with every one in laying out a railway—becomes especially difficult to guard against under two circumstances of frequent occurrence:

First, when a line of light traffic is to be carried through an inherently difficult country, so that the cost of construction must in any case be large. The tendency to look on a slight percentage of increase in cost as a trifling matter, although it may, nevertheless, involve an expenditure out of all proportion to the real advantage secured, is very strong, very difficult to avoid, rarely or never avoided altogether. *Per contra:*

15. *Secondly*, when a line of comparatively heavy traffic is to be carried through a region offering small natural difficulties, a dangerous tendency arises of an opposite character;—a tendency to unduly exaggerate the importance of a large percentage, and yet small aggregate of increased cost. This tendency is especially probable and dangerous when means for construction are limited, or when the margin of profit on the enterprise as a

whole is liable to be small: a fact which should not be permitted to exercise any influence whatever, except through its reflex effect on the rate of interest on capital. The most usual and most unfortunate form which an error of this kind can take is the adoption of unduly high gradients to effect a really trifling economy. The railways of the Western United States, as already noted, have suffered greatly from this cause.

The most experienced and cautious man cannot free himself wholly from these two grave errors; the inexperienced engineer or projector should therefore be continually on his guard against them.

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16. It has seemed essential thus to lay down certain preliminary generalities as to what should be the attitude of mind of a locating engineer, because he is often unconsciously and improperly guided in his actions by the mere bald feeling (whether justified or not does not matter) that his company is very rich or very poor, and that he can spend or must save accordingly. Supposing him to enter upon the work, therefore, with that most important of all preliminaries, a correct appreciation of the proper basis for decisions, the problem for which he is properly responsible, when selecting a route for a railway whose construction has been determined on, may be again subdivided thus:

First, and by very much the most important, is the selection of the general route between the two established termini, or, as very often happens, the selection of one or both termini as well.

Secondly comes the adaptation of the line in detail to the topographical conditions which exist along the route selected.

17. The question of general route is commonly settled by the RECONNAISSANCE, which for this reason must be classed as by far the most important duty of the engineer in charge, and the one for which it is most essential that he should qualify himself properly, which he can only do by learning to estimate and give due relative weight to all those circumstances which have or may have a bearing upon the future of the property, as well as

to judge of the physical possibilities of the route in question. Otherwise—if he is qualified merely in the latter respect—his danger is a double one: that he will give undue weight to purely engineering questions as against commercial and pecuniary advantages ; or, *vice versa*, that the desire to reach such and such a town or make such and such a connection may work injury to the property considered as a whole.

The reconnaissance, in the broad sense here given to the term, viz., the selection of the entire route between termini, or even in cases of the termini themselves, is rarely left entirely to the engineer or to any one person. But by whomsoever decided, there is the same danger of error from attaching undue importance to some, at the expense of other, governing considerations.

18. The art of correctly discerning in advance, by merely ocular examination, assisted only by maps and a few portable instruments, the physical possibilities and probable cost of a projected or possible railway route, and of making the most advantageous selection from the possible routes (which are always numerous) for further instrumental examination, is sometimes supposed and stated to be a sort of "natural gift," dependent upon an "eye for country," and to be acquired only and exclusively by practice.

As with most popular impressions, there is a foundation of truth in this. Certain natural qualifications and a considerable amount of practice are essential. Nevertheless, the acquirement of reasonable skill and competency for the discharge of this most responsible of all duties connected with laying out a railway is only to a limited degree dependent upon practice alone, or increased by long practice, and is hardly dependent at all upon any peculiar "natural gift," other than a natural gift for close observation, and for care in observing, collecting, and remembering those facts which are or may hereafter be important —qualities which are apt to be useful for other purposes as well. There are certain general rules and methods to be observed, and certain general dangers to be avoided, which can be laid down

almost as certainly as if the art of reconnoitring were an exact science, and which, if they be mastered in advance,—not simply by reading them, but by acquiring a habit of observation and of applying them to hypothetical instances,—will enable the young engineer of very limited experience to go into the field better guarded against error than by long years of field practice alone; for the latter, in location, as in most other matters which require something more than the mechanical application of methods learned by rote, is quite as apt to confirm erroneous opinions as to inculcate good ones. The first necessity is to form correct and definite ideas as to what a railway should be, what kind of a railway we are to build, what are the conditions which contribute most to its prosperity, and to what extent they so contribute, in order that the reconnoitring engineer may be prepared to form on the instant an approximately correct idea, not only as to what he can do, but as to what he ought to do, in any given case, and to decide which of two incompatible ends should be sacrificed to the other, and what approximate sum represents the difference in value between them. Otherwise the experienced and inexperienced man alike are in imminent danger of failing even to discern or consider what are really the most promising possibilities—not from lack of an "eye for country" or training in the field, but from wrong ideas of expediency.

19. It necessarily results from the preceding that the reconnaissance is, of all his duties, the one which the responsible engineer in charge should personally discharge, and never under any circumstances delegate, in part or whole, to less experienced subordinates, where the final decision may be seriously affected thereby.

The greater portion of this volume will be devoted to the presentation of data as to the first and most important of the duties connected with the reconnaissance and subsequent surveys, determining WHAT OUGHT TO BE DONE; afterwards considering the comparatively simple matter of how to do it.

20. To reach entirely correct decisions as to what ought to

be done requires, it is plain, that we should not only have a correct idea of the nature of a railway corporation's finances and of railway traffic, but that we should foresee exactly the volume and sources of the future traffic, and the details and probable amount of the future operating expenses, as well as in part of the future revenues; for the larger the probable traffic, the more perfectly adapted to its cheap handling can we afford to make every detail of the line; the larger the probable revenue, the less will the burden be felt of paying interest on present expenditures, etc., etc.

21. This we cannot do. To foresee such details perfectly is impossible. To foresee them in any degree we are obliged to do that most hazardous thing—to look forward to and "discount" the future; to make—and act upon—what is, after all, nothing more than a guess at the probable course of future events. To foresee the future with adequate exactitude even in the simple case of improvements on an old road is difficult, although we have a definite past to guide us. In the case of a new road it is still more difficult to approximate to, and still less possible to reach, an exact and positive result; but nevertheless, especially in any country where railways already exist, estimates of the financial importance of doing or not doing certain things can always be made, by proceeding on correct principles and using proper care, which shall be a sufficient guide for location, and hence, when made, should always be carefully followed in preference to mere "judgment" and guesswork pure and simple. The uncertainty as to the exact requirements to be fulfilled by the works when completed is a disadvantage, indeed, which cannot be escaped; but the more difficult it is to reach absolute correctness, the greater need we have of some guide which shall reduce the unavoidable guesswork to its lowest terms, and so save us from the manifold hazards which result from not only guessing at facts, but at the effect of those facts. Whatever care we use, we can never attempt with success to fix the exact point where economy ends and extravagance begins; but what we can do is to establish certain narrow limits in either

direction, somewhere within which lies the truth, and anywhere outside of which lies a certainty of error. Due judgment and caution require that we should do so; and this is what we do effect when we make as careful an estimate as possible of the details of the problem and accept the final result as an absolute guide.

The following three tables (1 to 3), while containing data otherwise useful, and to which we shall have occasion to refer, bring out vividly the enormous indirect benefits of railways, which have much to do with the construction of many lines otherwise profitless, as notably in Canada and Mexico, where the government has (very properly and wisely) paid heavy subsidies to secure the construction of otherwise profitless lines. The same has been true to a large extent in the United States, both as respects the general government, States, and private individuals and corporations. Nearly all the increase in the valuation of the United States since 1850, as shown in Table 2, may be said to be due indirectly to railways, since without their aid a much greater valuation than existed in 1850 would have been impossible.

TABLE 1.

ESTIMATED TOTAL WEALTH OF THE UNITED STATES.

[Abstracted from U. S. Census, 1880, Report of H. Gannett, Special Agent.]

ITEMS.	Total Amount, 1 = 1,000,000.	Per cent.
Railways and equipment	5,536	12.69
Farms	10,197	23.37
Residence and business real estate, including water-power	9,881	22.64
Telegraph, shipping, and canals	419	.96
Live-stock, farming tools, and machinery	2,406	5.51
Household furniture and personal clothing, etc.	5,000	11.46
Mines and quarries, including 6 mos. average output estimated as on hand	781	1.79
Three fourths of annual product of agriculture, manufactures, and importations, estimated as on hand	6,160	14.11
Churches, schools, and public buildings not taxed	2,000	4.58
Specie	612	1.40
Mechanics' tools and miscellaneous	650	1.49
Total wealth of United States, June, 1880	43,642	100.00

NOTE.—Including the mileage which was under construction at the time of the census, and money spent on abandoned grading, there may have been the equivalent of some

TABLE 2.

VALUATION PER HEAD AND TOTAL TRUE VALUATION OF EACH STATE OF THE UNITED STATES SINCE 1850, BY DECENNIAL PERIODS.

[Abstracted from Vol. VII. of 1880 Census. The valuations preceding 1870 include shares as personal property, so that much of the apparent falling off is fictitious.]

95,000 miles in the country, indicating that the average value placed on it is a little less than $60,000 per mile. This corresponds closely with the aggregate of stock and bonds per mile (Table 32), but it represents value and not cost, and the latter has probably not been over $35,000 to $40,000 per mile in cash, which would make the actual cost of the railways is not over 7½ to 8 per cent of the national wealth. Yet at least three quarters of the enormous aggregate may be said to be the direct result of railways, since without them it could never have existed. In other words, every dollar of cash invested in railways has on an average added $6 to $8 to the national wealth; a fact which has had much to do with the construction of railways which were not directly profitable.

TABLE 3.

RAILWAY CAPITAL AND PUBLIC WEALTH OF THE WORLD.

[Reconstructed and Revised from Mulhall's "Dictionary of Statistics."]

	Population, 1880.	Total Railway Capital. Millions.	Per Mile of Railway.	Per Inhabitant.	National Wealth. Millions.	Ratio of Railway to Total Capital.
	1 = 1,000.	$	$	$	$	Per cent.
United States	50,410	5,780	55,300	112	50.340	11.4
Canada	4.340	349	46.700	83	3,160	11.1
Australia	2,880	272	50,500	97	2,900	9.3
United Kingdom	34.650	3,740	203,000	117	42,300	8.8
France	37.430	2,400	133.000	63	39,200	6.1
Germany	45.260	2,270	102,300	49	30,700	7.1
Russia	84.440	1.500	99.500	19	19,860	7.7
Austria	37.830	1,286	100,300	34	19,000	6.5
Italy	28,910	524	94.200	19	10,820	4.8
Spain	16,290	383	79.600	24	7,620	5.1
Portugal	4.350	58	74.800	15	1,648	3.3
Belgium	5.480	296	109.200	53	5.720	5.3
Holland	4,060	131	90,300	34	5.450	2.4
Denmark	1,960	49	50.000	24	1,720	2.8
Sweden and Norway	6,560	155	32,000	24	3.580	4.3
Switzerland	2,810	160	97.200	58	1,502	10.7
Turkey, etc	17,250	117	64,600	10	3,490	3.3
Total Europe	312,990	13,069	117.200	39	192 600	6.7
Grand Total	370,620	19,470	84,700	49	249,000	7.8

The above statistics, except population, are mostly for the year 1882. Many errors and inconsistencies probably exist in this, as in all similar estimates. No great accuracy is possible in them.

According to Mulhall the wealth of Britain has more than doubled in the past 40 years, and quadrupled in 70 years. While the indirect benefits of railways have been far less in Europe than in the United States, it is tolerably certain that at least 40 per cent of the present wealth of Europe would not exist except for them.

CHAPTER II.

THE MODERN RAILWAY CORPORATION.

22. MODERN railway corporations, even the strongest of them, have but a narrow margin for mistakes. It is important that we should have that fact clearly before the eyes, and the reasons why it must be so, in order that the atmosphere of wealth which surrounds the period of construction may not beguile us into folly.

The origin of most modern railway corporations is, in its economic aspects, about as follows: A certain number of men conclude that, for any one of the reasons before considered, there is sufficient need of a railway in a certain region to make it, when completed, worth more than it has cost to those who have built it, so that a "profit," or creation of a greater value than the expenditure, will accrue to them.

Ordinarily, this sanguine expectation is at least so far justified that the property when completed is worth to some one, in one way or another, all or nearly all it has cost, although there may be no great profits. In any rapidly growing country, like the United States, the general rule—subject to numerous and painful exceptions—has been and is that railway properties, like other enterprises of the kind, tend to be very productive, and to eventually rise in value far above their real cost, often to many times their cost.

23. For this reason it has very frequently happened in the United States that enterprises have appeared to be of so sound a character that they have been almost immediately able to borrow on mortgage their entire capital for construction, or even a still larger sum, and the original projectors and true

"owners" of the property have not been required to invest anything whatever in the property themselves beyond their original sagacity in initiating the enterprise—a quality which has its value in railway business, as in most other human affairs. In all cases they can, if they choose, borrow on mortgage whatever sum they can make capitalists believe is or will be the minimum value of the property. Usually they not only choose, but are compelled to do this.

24. The original projectors, who alone appear in the management of the enterprise, and who alone constitute what is known as "the Company," then simply make good the deficiency, if there is any deficiency, in the means for construction; assuming what, in the general opinion, is the whole RISK of the enterprise. For taking this risk, as well as for their services in initiating and carrying on the enterprise, they obtain nothing more than what may be called the SPECULATIVE INTEREST, viz., that portion which fluctuates with and depends solely upon the skill and good judgment with which the property has been originally planned and is afterwards managed; which may be wiped out in a moment or may become very valuable.

25. This interest is in modern times supposed to be represented by the stock or (in England) "shares," although the line between stock and bonds or mortgage securities is not always sharply drawn. The proportion which the stock and bonds bear to each other varies greatly in different parts of the United States and of the world. In regions where capital is abundant, and there are small chances of either great loss or great gain, those who believe in the enterprise and would be willing to lend money on its minimum value will prefer to own it outright, and few or no mortgage bonds will be issued. Such is the case in England and on the Continent. In a country where the future is all uncertain, but where population and traffic is advancing, literally, by leaps and bounds, and where the future is so "discounted" (as it is all but inevitable that it should be) that lines are built, not for the traffic which exists but for the traffic which is to come, the opposite conditions will all but inevitably prevail.

The bonds themselves will then partake of a speculative character, and will involve as much hazard as large investors can be persuaded to consent to. Consequently there will be a constant tendency for roads to be "built on bonds," the bondholders being in fact sharers in the speculative risk, but to a less extent. The limits of doubt as to the future, between the maximum and minimum value of the property, being a large one, they knowingly assume a portion of this risk, leaving it to the nominal "Company" to manage the property, and trusting that they will manage it as skilfully as they can, as their own sole chance of reaping a profit for themselves.

These latter conditions are well known to obtain more fully in the United States than in any other considerable region of the world, and on that account it is, and not primarily from difference of laws or business habits, that the railway system of the United States has been built to so much larger extent than elsewhere on borrowed capital represented by bonds.

26. Under conditions involving so large an element of speculative uncertainty, as well as such great probabilities of ultimate profit, many abuses, much feverish excitement, many deceptive exaggerations both in good faith and in bad faith, much gaining of something from nothing, many cases of visionary folly, of sad disappointment and of deliberate fraud, are all but unavoidable; yet in the conditions themselves there is nothing either surprising or reprehensible or avoidable. We have seen, in a much exaggerated form, the same causes producing the same effects in the oil excitement of 1863–5, yet they were but the collateral evil effects of a movement in itself in every way healthy and normal, and they ceased with the period of rapid expansion and sudden and irregular profits.

So with the organization of our railways. The existing conditions, with all their collateral evils, are in the main healthy and natural; and whether good or bad, cannot be expected to materially change until the process of rapid development and advance in wealth has ceased, which will not probably be for many decades. Until that time railways will continue to be

largely built, as they are built, on bonds and faith and hope, with a narrow margin of financial safety.

27. It is often claimed that the existence of these conditions is an evidence and result of a greater national rashness in doing business, but this is true only to a limited extent. The main reason is that, owing to the rapid development of the United States, the margin of positive and certain value has seemed to capitalists to be larger, and the minus side of the speculative and dubious element, the proper allowance for possible depreciation, has appeared to be less. The same general law obtains, and always has obtained, throughout the world, that such properties are always built on borrowed money up to the limit of what is regarded as their positive and certain minimum. value. The risk only, the dubious margin which is dependent upon sagacity, skill, and good management, is assumed and held by the Company proper who control and manage the property.

Thus it happens that in America, and in an increasing degree throughout the world, the nominal "Company," which the engineer and all other officers serve, and which exercises full control over the entire property for the time being, although in theory it is the real owner of the property, is not such in fact. All it really owns is a contingent interest in the results of its own sagacity and skill in creating a property which shall be in fact worth more than what lending capitalists consider its *minimum* probable value. Their small payment for this contingent interest (if they pay anything at all) is precisely equivalent in its nature, although less objectionable morally, to what is called a "margin" on stocks—it is sufficient only to cover the financial risk of the enterprise, or the difference between the actual and necessary cost and the general estimate of the minimum value of the line when completed, which is represented by various forms of bonds.

28. The essential truth of this general summary is not decreased by the fact that, to be entirely correct, it should take note of many apparent anomalies and exceptions. Thus it not infrequently happens that the issue of "mortgage bonds," and

even the cash received for them, is alone far greater than the actual investment, and still more frequently that a large proportion of the bonds are "taken" ("convey" the wise it call) and held by the original incorporators. Usually, in such instances, the second or third or fifteenth mortgage bonds are in reality the *stock*, and represent the speculative interest dependent upon management; which in that case very properly controls the property, either in law or fact. In that case too, when the property is not a productive one and a necessity arises for more capital to enable it to hold its own, some new device, "prior lien" bonds or what not, is used to transfer the true mortgage interest, involving no risk, to new parties, in lieu of those who originally held it, or thought they did. *Per contra*, when the property has been successful, then begins the process of "watering," so called, i.e., increasing the stock or bonds by new issues until their total amount bears a nearer, or at least more satisfactory relation to the present value or productive capacity of the property, as distinguished from its original cost. There have not been wanting gross frauds and impositions in this practice, as is not unknown in other business matters; but in its essence it is an entirely legitimate and proper business transaction, in the nature of a capitalization or "salting down" of realized business profit, and belonging as justly to the holders of the property as the corresponding rise in the value of other real property. A certain argument, whose force in certain individual cases is universally recognized by intelligent men, can be made against the retention by the individual of all such "unearned increment," but in the general judgment of mankind the argument on the other side is immensely stronger. The only legitimate distinction in this respect between railway property and any other real estate is that the nature of its origin as a creature of the State justifies a demand that its monopoly powers shall not be used oppressively, to charge more than a fair equivalent for service, as measured by practice elsewhere or on other kinds of traffic, under similar circumstances; but the just increase in value of a well-located railway, which does not abuse its monopoly powers

to make unjust exactions, is fairly the property of the owners, however large, unless and until the public are prepared to insure the investors a certain minimum return as well as deny them the uncertain maximum.

It may be added, that the mortgage or bonding process is carried on to a greater extent in railway than other business, simply because, unlike most other business enterprises, a certain

FIG. 1.—DIAGRAM SHOWING THE FINANCIAL RECORD OF THE LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY FROM 1870 TO 1885.

considerable fraction, but only a fraction, of the income of their property is in the nature of a monopoly which no conceivable circumstances can destroy.

29. The annual interest on these various forms of mortgage, together with fixed rentals of leased property, which are of the same nature, constitute what are known as the FIXED CHARGES, by which a large proportion of net revenue is always absorbed

on the most prosperous properties—very frequently nearly the whole of it, and not unfrequently a good deal more than the whole of it, if all such charges were paid.

In tables immediately following, the fact that these are the conditions which actually exist is clearly brought out, and if they were more generally realized by engineers, and by railroad officers generally, during the period of construction, it can hardly be doubted that it would lead to more careful study of the art of obtaining the utmost possible value from the money expended; but there are few men who are not elated and, as it were, intoxicated by having their pockets full of borrowed money, even when the responsibility is all their own, and on so small a scale that its length, breadth, and depth can be readily grasped. When the further danger is added of dividing up the responsibility among a dozen or more, each of whom sees millions in sight, which in his eyes are "the Company's," and not the Company's creditors', and a small part of which will suffice for all possible requirements of his department, the impulse to spend money freely may well become too great for average human nature to resist; so that the enormous sums of borrowed money *handled* during construction will create an atmosphere of wealth leading to a rash improvidence, which has been the chief cause of the bankruptcy of many lines. As the engineer has the first "whack" at the Company's funds, and at a time when the judgment of the coolest men is most likely to be tossing about on the dancing waves of a "boom" at its very height, his danger is particularly great; and he especially should realize that THE

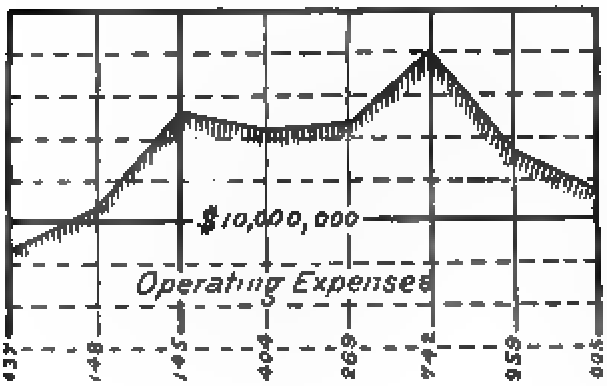

FIG. 2.—DIAGRAM SHOWING THE FINANCIAL RECORD OF THE MICHIGAN CENTRAL RAILROAD (INCLUDING THE CANADA SOUTHERN), 1878–1885.

RULE with new American railways is, and must continue to be, that a very moderate percentage of difference in either the first cost, or the operating expenses, or (above all) the revenue, means to the original projectors, whom alone he serves or knows, all the difference between success and failure.

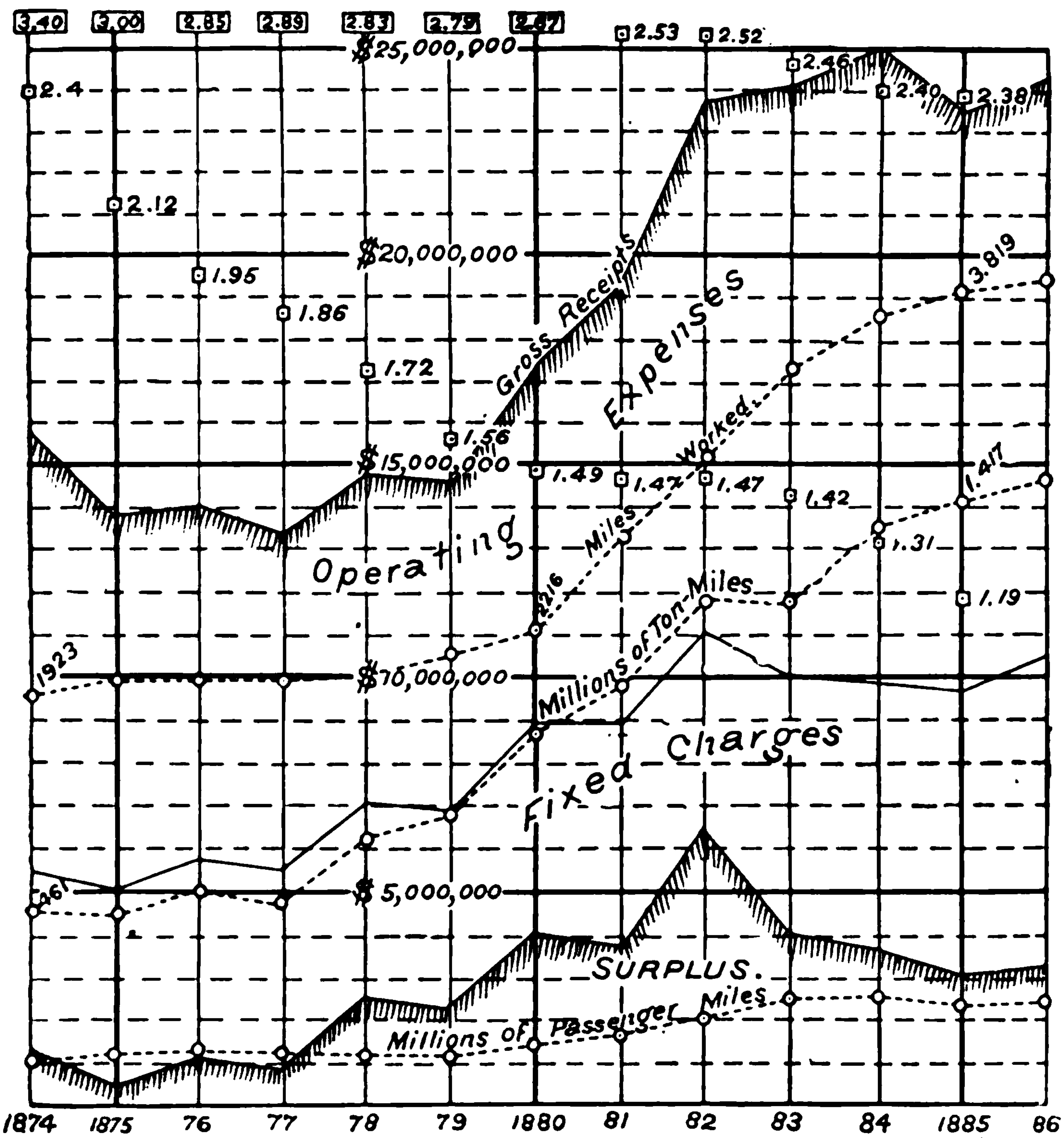

FIG. 3.—DIAGRAM SHOWING THE FINANCIAL AND TRAFFIC RECORD OF THE CHICAGO & NORTH-WESTERN RAILWAY, 1874–1886.

[Figures in squares, or points surrounded by squares, give the receipts per ton-mile and passenger-mile; the lower figures being those per ton-mile.]

In Figs. 1, 2, and 3 is shown graphically how very small is the margin of profit which makes the difference between solvency and insolvency even in the

soundest companies. These lines have not been chosen as specially marked examples of the ordinary fluctuations, but on the contrary are naturally very strong properties—so good that their stock has ranked for years together among the best investment securities. Yet out of the millions which they take in yearly it will be seen how small a margin is left over for distribution to the stockholders in many years, and what a heavy percentage of advantage to the stockholders results from a very small percentage of increase in the gross receipts, or of decrease in the operating expenses or (in much less degree) fixed charges. THE gain of all gains for a railway to secure will be seen to be additional revenue.

30. In fact, the situation is somewhat worse than if the Company merely began business with a heavily mortgaged property owned in fee. The theory that the Company is the owner in fact, as it is in form, of the entire property, and has simply placed certain mortgages upon it, is convenient and in a sense true; but it more correctly corresponds with the real facts which prevail in the United States, and for the most part throughout the world, to consider that the mortgage interest itself builds and owns the real property, as a man might build a house or factory to rent to others, induced thereto by the allegations of the managing Company that in that case they can and will earn and pay a fair or a large rental on the property from the profits of the business which they propose to carry on with the property and plant furnished.

31. This is the truer manner of looking at the facts, both because the "mortgage" is ordinarily far in excess of the mortgaging value of the property as property, closely approximating to and often exceeding its cash cost, and because the property itself is all but absolutely worthless except for the one particular business which it was built to carry on, so that the loan or mortgage involves the determination that the property on which the money is lent is worth its cash cost for any one to "operate," if the managing company should fail to do a profitable business with it. And as the full cost of all the fixed property is then always (practically) advanced, and frequently the cost of all, or most of, the portable plant (rolling stock) in addition, the nominal mortgage interest is so large that it really amounts practi-

cally to an ownership interest in the real property; and all that the mortgage interest does not own is the immaterial franchise, which necessarily goes with the property when and if they assume control of it. This is the additional security which makes the nominal mortgage interest a real one, except that usually, the operating company are obliged either to invest some money themselves in plant to borrow the rest of it, or to throw in an interest in the business (stock) in order to persuade outsiders to build the plant. Very frequently,—in fact—usually, individuals in the operating company (stockholders) also lend money (buy bonds) for the erection of the plant.

32. The instances where the original projectors, even of lines which have ultimately proved well justified and highly successful, have been ruined by depleting their means too rapidly with unwarranted or deferable expenditures, and have been compelled to yield their control of the property, almost on the eve of its success, have been very numerous. A single instance, selected almost at random, of the startling vicissitudes to which such properties are subjected, and of the dangers of the most meritorious enterprises from the long periods of depression through which they usually have to pass soon after their construction, and from the scanty means of the original projectors, may be instructive.

33. Within a few years after its construction, what has since become the St. Paul, Minneapolis & Manitoba Railway, then the St. Paul & Pacific, was a very striking example of such reckless management of railway investments.

Its construction began in the flush times of 1872–3. Working then 318 miles, it earned only $630,000 gross and $166,000 net, the latter being at the rate of only $523 per mile of road. Its debt (exclusive of stock) was then over $50,000 per mile, and, no interest being paid on any part of it, a receiver was appointed.

In 1873–4 and 1874–5 the net earnings were still less.

In 1876–7, an extension of 104 miles into the Red River Valley having been completed, the net earnings were nearly doubled, and became $749 per mile.

By 1878, although the bonds of the Company had become almost

worthless, the receiver succeeded in completing the line to the Dominion boundary, in time to save a large land grant, and the better days of the property began to dawn ;—five years too late for the original projectors.

A new company was then organized, purchased the line at foreclosure sale, and found itself the possessor of the 422 miles above specified, and 143 miles more, with a bonded debt of only $7,266,000—less than $13,000 per mile. Then first the land grant began to be of immediate value. Immigration was flowing in, the Canada Pacific was building beyond it, wheat began to rise, and a property which had been almost worthless, all at once became very productive.

The boom continued until 1883, and its progress is shown in Table 4.

TABLE 4.

FINANCIAL HISTORY OF THE ST. PAUL, MINNEAPOLIS & MANITOBA RAILWAY.

YEAR.	Miles.	EARNINGS. Gross.	EARNINGS. Net.	Pass. Miles (Millions).	Fr'ght. Miles (Millions).	Land Sales. Acres.	Aver'ge Rate, Cents per Ton.	Dividends. Per Cent.
1872–73.........	318	$1,980	$522	....	....	... .	....	......
1874–75.........	318	......	......	....	....	....	....	......
1876–77..	422	......	749	....	....	... .	....	... ..
1879–80.........	1,497	$4,471	$2,489	....	....	268,700	....	......
1880–81.........	1,497	4,954	2,607	25.4	93.4	97,900	2.88	......
1881–82........	1,497	7,159	3,573	54.4	190.	203,300	2.52	6½
1882–83.........	1,497	7,605	3,995	68.1	341.	104,250	1.91	9½
1883–84.........	....	5,992	3,282	53.5	340.	83,900	1.79	8
1884–85...	....	5,230	3,057	45.0	395.	65,600	1.52	6½

By the end of 1883 the road was earning net more than any road westward of Chicago except two (the Rock Island and Chicago & Alton), and the boom was at its height. The real surplus in the last two years had been enough to pay nearly twice as great dividends. Its lines were well placed, and almost completely secured to the Company the possession of the traffic of one of the most fertile valleys on the Continent.

Then an ebb-tide set in. Immigration and the price of wheat fell off, as also the immense traffic from the construction of the Canada Pacific. A competing line on the north shore of Lake Superior was opened. Rates were necessarily made much lower, and for the two additional

years, which alone can be given in this volume, the record was as shown in the last two lines of Table 4, the contrast between which and the last year of the flush period is notable.

In the last year, in spite of the falling off in prosperity, which had in it no element of immediate disaster, bonds to the amount of 50 per cent of the stock were "sold" to stockholders for 10 cents on the dollar, which was, of course, equivalent to a dividend of some 45 per cent, more if the future of the property did not belie its promise. From the point of view of the public interest there was no danger of this. Its future was magnificent and assured. As respects the individual owners, great as had been their profits to date from securing control of this formerly bankrupt property, this was and is far less certain.

34. The instructive feature of the example is that even now (1885), failing any one of these following conditions, ruin or serious loss of all *recent* investors in the stock of property would be near at hand:

1. The fixed charges are only $1358 per mile, whereas double that figure or even more would be more usual. At the latter figure a combination of many causes might bring the net earnings below it.

2. The rapid fall of rates, which otherwise would have extinguished the surplus, was met by important improvements of the main-line grades, and by the introduction of more powerful locomotives, as well as by the natural economies resulting from heavier traffic, so effectually, that in the last year but one of the table 24 per cent more freight was moved without any increase of engine mileage.

3. The revulsion occurred at a time when the general depression of business was not marked, when the Company was not embarrassed by excessive obligations for new construction, and when the falling off in traffic and revenue was in no respect panic-like. Otherwise, even as sound a property as this had proved itself to be, had it entered upon considerable expenditure for new construction or improvement, based on a standard conforming to the present large earning power of the property *as a whole* instead of the probable earning power of the additions, separately considered, might well have found itself again a bankrupt.

35. That such contingencies and fluctuations are not exceptional, is indicated by the aggregates of railway foreclosures, shown in Table 5, which in 1885 rose to the aggregate of 2880 miles with $139,658,000 in bonds ($48,500 per mile) and $120,090,000 in stock ($41,700 per mile) or $268,213,000 in all ($93,136 per mile) the bonds alone probably representing, as is so com-

TABLE 5.

RAILWAY FORECLOSURES.

YEAR.	Miles.	Capital Stock. 1 = 1000.	Funded Debt. 1 = 1000.	Floating Debt. 1 = 1000.	Total. 1 = 1000.
1881..........	2,617	$51,278	$76,645	($10,000?)	$137,923
1882..........	668	20,751	23,999	10,074	54,824
1883..........	1,190	24,588	38,198	2,482	65,268
1884..........	714	12,894	13,061	423	26,378
1885..	2,880	120,090	139.658	8,465	268,213
Total, 5 yrs...	8,069	$229,601	$291,561	$31,444	$552,606
Per mile, average........		$28,455	$36,135	$3,897	$68,487
Per mile, 1885............		$41,697	$48,499	$2,940	$93,136

The above is compiled from "Poor's Manual," 1886. It is unquestionably full of errors, but no authentic or complete figures exist. The general fact that the bonds and stocks of bankrupt lines run a good deal higher than those for solvent lines is clear, as the most serious errors are probably in the earlier years.

The *Commercial and Financial Chronicle*, in its October, 1884, *Investors' Supplement* presented a valuable table showing the railway companies now in default on payment of interest on bonds. Only railways in the United States are included, Mexican and Canadian lines being omitted, and only the particular issues of bonds are taken on which default is made, although the mileage given includes all operated by the defaulting companies. The table includes all companies defaulting during the period covered, which had not resumed payment in full, and which had not been foreclosed and reorganized. The totals are summed up in the following table, in which comparison is made with the defaults of 1873–76:

	Mileage.	Amount of Bonds.
Total defaults, October, 1884......................	15,986	$315,283,000
Entire railroad system of U. S., Jan. 1, 1884.......	121,592	3,455,040,283
Per cent of defaults to total......................	13.14	9.12
Total defaults. 1873–1876..........................	......	$783,967,665
Entire railroad system Jan. 1, 1876................	74,096	2,175,000,000
Per cent of defaults to total......................	......	36.04
Increase in mileage and bonds during five years preceding Jan. 1, 1884..........................	39,818	$1,157,249,467
Increase in mileage and bonds during five years preceding Jan. 1, 1876..........................	21,232	*636,960,000

* Estimated at $30,000 per mile.

The whole number of companies in default in 1884 was only 42, against 197 in the former period. In the former period of defaults, about 20 companies out of the total 197 that were embarrassed were old railroads that were well established and once had a paying business. In the later period, out of 42 companies named in the table, none can be fairly said to have had a well-established and paying business on the basis of their present lines and existing liabilities, unless such companies as Erie, Wabash, and Reading be classed in that category.

On British railways, which are subject to far fewer vicissitudes than those of the United States, the average dividend of 4¼ per cent is divided approximately as follows,—United States statistics from the census of 1880 being added for comparison:

United States.	*British.*	
18.8	16.1 per cent pays	no dividends.
	1.0 " " " . . .	under 1 per cent
10.2	4.9 " " " . . .	" 2 " "
9.2	3.2 " " " . . .	" 3 " "
3.1	7.3 " " " . . .	" 4 " "
2.5	23.4 " " " . . .	" 5 " "
5.7	21.7 " " " . . .	" 6 " "
6.5	20.0 " " " . . .	" 7 " "
6.5	1.0 " " " . . .	" 8 " "
7.4	0.4 " " " . . .	" 9 " "
3.4	0.4 " " " . . .	" 10 " "
3.9	0.6 " " " . . .	about 15 " "

While exact figures on which to base a judgment are not available, it is not probable that more than one fourth of the existing mileage of the United States has escaped foreclosure proceedings or default on bonds necessitating a receivership. Many roads which are now among the strongest properties have been through such difficulties several times in their earlier history; while, on the other hand, many others, like the Denver & Rio Grande, Philadelphia & Reading, and other strong properties whose future seemed assured, have been overtaken by disasters resulting in great part from the intoxication of long-continued success. So that the properties are few indeed—and those mainly the ones which build no new lines—of which it can be predicted with any certainty that they may not become insolvent in the next period of serious depression.

TABLE 6.

ESTIMATE OF FUTURE RAILWAY CONSTRUCTION IN THE UNITED STATES.

[Prepared by Edward Atkinson, of Massachusetts, for various groups of States as described on next page.]

GROUP OF STATES.	Mileage still needed from Jan. 1, 1881. 19 years.	Mileage built from Jan. 1, 1881, to Jan., 1885. 4 years.	Per cent total estimate built in 4 years.	Mileage still needed before A.D. 1900. 15 years.
Class I..........	36,236	8,597	24	27,639
Class II................	27,199	5,282	19½	21,917
Class III....	34,472	8,351	24	26,121
Class IV...............	9,652	2,893	30	6,759
Class V................	9,888	5,857	59	4,031
Totals................	117,447	30,980	26.3	86,467

monly the case, somewhat more than the actual total expenditure to create the entire property. This amounts to nearly three per cent of the mileage, and over four per cent of the capitalized cost of the entire railway system of the country, and that too in a year which was in no respect a particularly bad one financially, as will be seen from Table 5, which gives similar figures for several years back.

36. The fact, illustrated by the history just given of a road in the far West, that the intoxication of realized success will lead even prosperous companies to assume dangerous and reckless liabilities, becomes especially important in view of the fact that in the future a large portion of the new mileage will be constructed by such lines. A carefully studied forecast of the probable mileage to be constructed, by Mr. Edward Atkinson, made in 1881, and confirmed as a moderate and cautious estimate which will almost certainly be exceeded by experience up to 1885, brings out this fact clearly, in addition to having an interest of its own, and is given in Table 6.

DESCRIPTION OF GROUPS, TABLE 6.

Class I. consists approximately of the 11 States lying in or on the irregular pentagon marked out by Boston, New York, St. Louis, Louisville, Washington—estimated to have by 1900 *one mile of railway per* 4 *square miles*, as now in Massachusetts.

Class II. consists of the 10 States lying immediately to the north, west, and south of Class I., stretching down the Atlantic coast to Florida, estimated to have by 1900 *one mile per* 8 *sq. miles*, or half of Class I.

Class III. includes 11 States in the far West and South, with *one mile per* 16 *sq. miles*, or half of Class II.

Class IV. includes the 5 States of Maine, Nevada, Colorado, Oregon, and California, with *one mile per* 32 *sq. miles*, or half of Class III.

Class V. consists of Florida, Dakota, and 7 other Territories, with *one mile per* 64 *sq. miles.*

Total United States mileage when estimate was prepared, 91,778; estimated total, 1900, 209,225 miles. This estimate assumes an average future construction for the 15 years after 1885 of 5,764 miles against an average of 7,745 miles per year for the previous 4 years. The estimate is almost certain to be largely exceeded.

TABLE 7.

PROGRESS AND EXTENT OF THE RAILWAY SYSTEM OF THE WORLD.
[Revised from Mulhall's "Dictionary of Statistics."]

	MILES OPEN.					COST (millions, $).			
	1840	**1850**	**1860**	**1870**	**1880**	**1850**	**1860**	**1870**	**1880**
United States...	2,818	9,021	30,635	52,914	93,349	292	1,094	2,332	5,070
United Kingdom	838	6,621	10,433	15,537	17,945	1,166	1,685	2,572	3,640
Continent.......	1,074	8,311	21,815	49,320	86,818	652	1,730	4,320	8,690
Canada, etc.....	....	538	4,228	12,339	31,804	34	243	860	2,010
Total.........	4,730	24,491	67,111	130,110	229,916	2,144	4,752	10,084	19,410

TABLE 8.

RAILWAYS OF THE WORLD, JANUARY 1, 1884.

[From Prof. A. T. Hadley's "Railroad Transportation, its History and its Laws."]

	Miles.	Capital Invested.	Per Mile.
America	140,000	$8,400,000,000	$60,000
Europe	114,000	16,110,000,000	115,000
Asia	11,600	775,000,000	66,000
Africa	3,400	240,000,000	70,000
Australia	6,500	325,000,000	50,000
	275,500	$25,850,000,000	$72,200

	Length, Jan. 1, 1884.	Per cent Increase in 5 years.	Miles of Road to 100 sq. miles.	Miles of Road to 10,000 inhab.	Cost per mile. Dollars.
Germany	22,300	8	10.6	4.9	105,000
Great Britain and Ireland	18,600	5	15.2	5.3	204,000
France	18,500	18	9.0	4.9	128,000
Russia	15,700	7	0.8	1.9	80,000
Austria and Hungary	12,800	12	5.3	3.4	105,000
Italy	5,900	13	5.1	2.0	92,000
Spain	5,100	16	2.6	3.0	78,000
Sweden	4,000	14	2.3	8.7	30,000
Belgium	2,600	6	23.2	4.8	132,000
British India	10,500	20	0.7	0.4	66,000
United States	120,000	43	3.4	22.5	61,000

		Equipment per 100 miles.			Pass. Moved (Millions).	Tons Moved (Millions).
		Locom.	Pass. cars.	Freight.		
Germany	1882	51	95	1,081	224	198
Great Britain	1882	76	232	2,298	655	291
France	1881	46	105	1,207	180	93
Russia	1881	40	50	775	33	14
Austria	1882	30	62	716	47	70
Italy	1882	29	88	510	34	11
Spain	1880	26	77	468	15	9
Sweden	1881	16	36	401	7	5
Belgium	1881	72	139	1,840	57	37
British India	1883	24	65	436	65	19
United States	1883	22	21	663	313	400

Comparison with Table 10 and others will show that there is considerable uncertainty in these figures. It should be remembered that American rolling-stock is much heavier and larger than foreign, and that the average distance over which each passenger or ton is moved is far greater.

TABLE 9.

PROGRESS OF AMERICAN RAILWAY CONSTRUCTION BY GROUPS OF STATES, AND OF FOREIGN RAILWAY CONSTRUCTION.

	1850	1855	1860	1865	1870	1875	1880	1885
Six New England States..........	2,508	3,469	3,660	3,834	4,494	5,638	5,977	6,310
New York, New Jersey, Penna..	2,807	4,849	5,841	7,594	9,709	12,639	13,865	16,973
Delaware, Maryland, W. Virginia	395	624	865	945	1,282	1,816	2,005	2,566
Virginia, N. Ca., S. Ca., Ga., Fla.	1,620	3,294	5,111	5,228	6,094	7,047	7,803	11,127
Alabama, Miss., La., Tenn., Ky..	415	1,523	3,726	3,901	5,135	6,240	7,008	9,675
Ohio, Michigan, Indiana, Illinois.	1,256	4,173	8,684	9,646	13,177	18,879	21,964	27,101
Wisconsin, Minnesota, Dakota, Iowa, Nebraska, Kan., Mo....	20	394	2,380	3,201	9,506	14,903	22,259	31,527
Indian Ter., Arkansas, Texas, Colorado, Wyoming, Montana.....	.....	40	345	503	1,583	3,966	6,582	13,734
Pacific States and Territories....	.....	8	23	233	1,934	2,968	5,886	9,954
Total United States............	9,021	18,374	30,635	35,085	52,914	74,096	93,349	128,967

The above was computed from the tables in various issues of "Poor's Manual," which also gives data for the following tables, corrected yearly.

FOREIGN COUNTRIES.

	1840	1845	1850	1855	1860	1865	1870	1875	1880	1884	1888	End of 1890
Great Britain.	838	2,536	6,621	8,335	10,433	13,289	15,537	16,658	17,933	18,851	19,920	.....
France.	271	551	1,879	3,459	5,900	8,477	10,904	12,339	14,839	19,243	21,912	22,570
Germany.....	340	1,429	3,747	5,138	7,212	9,105	12,136	17,317	20,900	22,812	25,313	......
Canada.......	......	......	38	1,218	2,173	2,231	2,679	4,899	6,887	9,571	......	13,275

TOTAL MILEAGE OF RAILWAY CONSTRUCTED AND IN OPERATION IN THE UNITED STATES, FOR EACH YEAR FROM THE BEGINNING OF RAILWAY CONSTRUCTION.

	0	1	2	8	4	5	6	7	8	9
1880.............	23	95	229	380	633	1,098	1,273	1,497	1,913	2,302
1840.............	2,818	3,535	4,026	4,185	4,377	4,633	4,930	5,598	5,996	7,365
1850.	9,021	10,982	12,908	15,360	16,720	18,374	22,016	24,503	26,968	28,789
1860.............	30,626	31,286	32,120	33,170	33,908	35,085	36,801	39,250	42,229	46,844
1870.............	52,922	60,293	66,171	70,268	72,385	74,096	76,808	79,088	81,767	86,584
1880.............	93,296	103,143	114,712	121,455	125,379	128,363	136,400	149,279	156,204	161,397

ANNUAL INCREASE.

1830.............	....	72	134	151	253	465	175	224	416	389
1840.............	516	717	491	159	192	256	297	668	398	1,369
1850.............	1,656	1,961	1,926	2,452	1,360	1,654	3,642	2,487	2,465	1,821
1860.............	1,837	660	834	1,050	738	1,177	1,716	2,449	2,979	4,615
1870.............	6,078	7,379	5,878	4,097	2,117	1,711	2,712	2,280	2,679	4,817
1880.............	6,712	9,847	11,569	6,743	3,924	2,984	8,037	12,879	6,925	5,193

TABLE 10.

MILEAGE, COST, ETC., OF EUROPEAN RAILWAYS, WITH TOTAL COST OF CONSTRUCTION AND AVERAGE COST PER MILE.

[Rearranged and recomputed from the *Revue Générale des Chemins de Fer*, 1886.]

COUNTRY.	Miles. 1883-5.	Cost. Millions.	Av. Cost Per Mile.	Sq. Miles per Mile Ry.	Per Cent Increase, One Year.
				Eng.... 4.4	2.03
United Kingdom....	18,864	$3,895.10	$206,490	Scot... 10.3	1.29
				Ire.. ... 13.0	2.01
				6.5	1.91
Belgium........................	1,885	334.45	177,420	4.2	2.13
France........................	16,578	2,232.20	134,640	11.1	2.05
Germany...........	21,785	2,248.40	103,210	9.4	2.07
Austro-Hungary................	12,603	1,279.80	101,550	Aus.... 14.7	2.98
				Hung.. 24.0	3.12
				18.8	3.04
Switzerland.....................	1,795	184.88	103,000	9.2	3.66
Spain...........................	4,550	442.26	97,200	38.3	3.30
Portugal........................	927	90.11	97,200	37.9	4.98
Russia...	14,226	1,382.30	97,168	130.5	5.72
Italy.......	5,871	554.50	94,448	18.5	4.86
Holland	1,406	127.34	90,918	9.7	3.21
Sweden	3,975	59.34*	41,563	41.7	1.12
Denmark........................	926	37.00	39,961	13.0	1.80
Norway.............	970	33.51	34,548	127.0	1.97
	106,361	$12,901.19	$121,300	32.9	3.07
GERMANY IN DETAIL—					
Prussia........	12,636	1,309.40	103,620	10.2	2.13
Bavaria.	2,833	268.39	94,728	9.4	1.76
Saxony.........................	1,434	149.35	104,150	4.4	2.36
Wurtemburg....................	968	110.95	113,140	8.4	2.24
Baden	818	99.70	121,880	7.0	1.95
Alsace-Lorraine............... ..	....	....	....	....	....
Other German States	3,096	310.61	100,328	8.4	1.96
Total Germany	21,785	2,248.40	103,210	9.4	2.07
MINOR EUROPEAN COUNTRIES—	Kilos.				
Bosnia and Hertzegovina........	370	....	....	87.0	5.14
Bulgaria.	222	....	....	179.0	14.55
Finland.........................	1,181	....	....	196.0	2.92
Greece	22	....	....	1800.0	147.00
Luxemburg......	366	....	....	4.4	0.97
Roumania........................	1,503	....	....	53 9	5.73
Turkey..........	1,173	....	....	111.5	7.54
	4.837	(some 3,000	miles).		

* There is an error in this sum, which should be about $100,000,000 greater—150.66.

The last three columns are taken (converting metric into English units) from the *Statisque des Chemins de Fer de l'Europe*, 1882. Vienna, 1885.

According to other, and perhaps more authentic figures, the railways of Great Britain have cost $205,842 per mile of road; the Belgian State Railways, $123,986; for the French railways, $124,642; for the German State Railways, $105,204; the German private roads, $71,877; the Austro-Hungarian roads, $104,420. The cheapest system of Europe is the State Railways of Finland, $30,102; the other Russian railways stand at $82,244, against $63,250 per mile for the railways of the United States.

The whole cost of the railways of the world has been more than $24,000,000,000, which,

however, is only about $24 per inhabitant. In this country the expenditure has been about $133 per inhabitant; in Great Britain, $107; in Germany, $47; in France, $57; in Austria-Hungary, $33; in Italy, $19; in Belgium, $41; in Sweden, $25; in Spain, $29; in Russia, $14; in Canada, $89.

In France and Germany railways pay about 5 per cent on the capital invested, as an average; in Great Britain, 4 to 4½; in all Europe and in the United States, about 4 per cent.

TABLE 11.

EXTREME FLUCTUATIONS IN PRICE OF THE STOCKS OF VARIOUS COMPANIES OF GREAT NATURAL STRENGTH.

The lowest points in times of depression (distinguished by an **l**) and the highest price in times of activity (distinguished by an **h**) are alone noted, except that in the last column is given the price in November, 1886. The list has been selected almost at random, regardless of their actual financial status, to include the more prominent companies which, from the nature of their traffic or other strategic advantages, might naturally be expected to be (as for the most part they are) least subject to erratic fluctuations of value.

COMPANY.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.
New York Central	l 103¾	......	h 155⅝	......	......	......	......	81¾	113⅝
Erie	l 7⅝	......	......	h 52⅞	......	l 26⅞	......	l 9¼	35¾
Pennsylvania	......	......	l 96	h 140¼	......	......	......	l 91½	114¾
Baltimore & Ohio	l 75	......	......	h 210	......	......	......	l 165	......
Central of New Jersey	l 13⅛	......	......	h 112	......	l 68¼	......	l 31	......
Boston & Albany	l 129	......	......	h 175⅛	......	h 185	......	l 169	197
Lake Shore	l 55⅞	......	......	h 135¾	......	......	......	l 50¾	96¼
Michigan Central	l 58½	......	......	h 130⅛	......	......	......	l 46½	96
Canada So.	l 38	......	......	h 90	......	......	......	l 23	64⅝
Pittsburg & Ft. Wayne	l 85	......	......	h 142	......	......	l 119½	h 142	145
Chicago & Alton	l 66¾	......	......	h 156	......	......	l 118	h 140	143½
Ch., Burlington & Q.	h 99¼	......	......	h 182½	......	......	l 107	h 138⅛	140½
Ch., Milw. & St. P.	l 27½	......	......	h 129¼	......	......	......	l 64¾	95
Ch. & N. Western	l 32½	......	......	h 136	h 150¾	......	l 81½	......	120
Ch., Rock Isl. & P.	l 98⅝	......	h 204	......	......	......	......	l 105	128
Ill. Central	l 72⅝	......	......	h 146½	h 150½	......	l 110	h 140	133⅛
Atchison, Topeka & St. F.	......	l 81¾	h 152¾	......	......	......	l 59½	h 89½	96
Denver & Rio Grande	......	......	l 61½	h 113¼	......	......	......	l 4⅝	33¾
Central Pacific	......	......	l 63	h 102⅞	......	......	......	l 26½	47½
Union Pacific	l 61¼	......	......	h 131¾	......	......	l 28	h 62¾	62½
Louisville & Nashv	l 35	......	h 174	l 79	h 100¾	......	......	l 22	61⅝
New York, N. H. & Hartf.	l 153¼	......	......	h 190	l 168	......	......	h 204	......
No. Pacific	......	l 16	......	......	h 54⅝	......	l 14	h 31¼	29⅛

The above extremes are in many cases brought about temporarily only by the machinations of speculators. In many cases permanent changes in the nature of the company have also had great influence. On the other hand, these fluctuations of stock are far less than the fluctuations in the productiveness for the time being of the properties represented by them, for the price of a stock—neglecting the mere momentary fluctuations of a few points forced for the sake of a "turn"—is, at the most, merely this: It is the speculators' estimate of what permanent investors feel for the time being to be the PERMANENT AVERAGE value of the stock. For there are always large holders who keep in mind the average value of the property during good times and bad times alike, and who will buy or sell in quantities large enough to immediately affect the price if THEY THINK it is falling below the present worth of its future chances, all uncertainties included.

TABLE 12.

ROLLING STOCK PER MILE IN THE UNITED STATES AND BRITISH COLONIES.

NAME OF RAILWAY.	Per 100 Miles of Railway Open.		
	Locomotives.	Passenger Cars.	Freight Cars.
New England States, 1883	28.76	48.31	635.9
Middle States, 1883	41.93	45.34	1714.5
Southern States, 1883	13.32	12.06	283.2
Western States, 1883	16.23	13.74	483.4
Pacific States, 1883	9.63	12.06	191.8
Canadian Pacific, 1885	10.9	10.1	276.2[1]
Intercolonial of Can., Halifax to Quebec, 1884	19.2	28.4	513.3[2]
Indian, 5 feet 6 inches gauge	27.2	66.5	512.2
India, metre gauge, 1884	20.4	69.2	369.7
Ceylon Government, 1883	31.8	95.6	296.1
Mauritius Government, 1884	40.9	131.8	500.5[3]
Queensland Government, 1882	7.9[4]	11.6	112.8
New South Wales Government, 1881	23.4	53.2	487.1
Victorian Government, 1882	16.8	33.6	291.6
South Australia Government, 1881	13.6[5]	22.1	344.9
New Zealand Government, 1883	15.0	42.7	453.2
The Cape Government, 1882	23.4	41.2	374.8
Average of totals	19.86	23.89	590.5

[1] Only partially open for traffic. [2] Opened about 1876.
[3] Freight traffic heavy during crop season.
[4] Report states, "We have been extremely short of engines all through the year."
[5] Report states that more locomotives are required.

Condensed from a paper on "The Laying-out, Construction, and Equipment of Railways in Newly-Developed Countries," by James Robert Mosse, M. Inst. C.E., in *Transactions* Inst. C.E., 1886. See also Table 8.

CHAPTER III.

THE NATURE AND CAUSES CONNECTED WITH LOCATION WHICH MODIFY THE VOLUME OF RAILWAY REVENUE.

37. WITH the invention of the railway began a new industry—the MANUFACTURE OF TRANSPORTATION. Transportation, indeed, existed before its invention, just as cotton cloth existed before the invention of modern machinery, but it was in each case mainly produced on a small scale by each consumer for his own use and his immediate neighbors'. With the invention of the railway first began the manufacture of transportation for sale on a large scale and by modern processes.

38. A railway corporation such as has been just considered—the typical modern corporation—exists for this purpose. It finds itself, on completion of its works, in possession of a certain piece of improved real estate, of certain buildings and fixed machinery (the track), and of certain tools and machines (the rolling-stock) for the manufacture of its commodities, together with certain establishments (the locomotive and car shops) for the maintenance and repair of its machine-tools, which the extent of its business requires. In many instances it has not a dollar's worth of ownership interest in all this costly plant, excepting a portion of the minor machinery, but simply controls it at, in effect, a fixed rental (interest and other fixed charges). All that it really owns is, commonly, a portion of the business or franchise; and this latter has likewise been hypothecated, or pledged, in the mortgage bonds as security for the payment of its rent charges. As this business has, from the nature of railway business, assurance of always amounting to a certain minimum at least, this franchise alone has a value as security which no ordinary business would have, and in a rapidly growing country its

existence enables all or nearly all of the actual cost of the entire premises and plant to be borrowed, or rented, from others.

On the premises so rented, the corporation carries on, for its own benefit, the business of manufacturing and selling transportation, so to speak, at wholesale and retail, in lots to suit the purchasers. Since it owns the business only, and has, as a corporate body, no interest or ownership in the property itself, it will be clear, and should be fully realized, that ALL its interests are limited to the narrow debatable ground which lies between doing the best possible and doing the worst possible with the property in hand, which is in all ordinary cases simply lent to them for an annual consideration.

39. Now, continuing the parallel, which will perhaps help to enforce the truths required, and referring only to sales of transportation, or revenue: if a manufacturing company in such circumstances should, in planning its works, so plan them as to cut itself off from disposing of certain lines of goods which it manufactures, or should place its retailing establishments (stations) at inconvenient points, it is clear that it would have seriously handicapped itself, even if, perchance, justifiably. This a railway company does when, by failing to run close to any accessible towns, it is prevented from furnishing them with transportation, or is so far away that sales are inconvenient. If it strives to shorten its line it is, for certain parts of its traffic, trying to sell less *yards* of its goods, at a certain price *per yard*, in order to save the cost of its manufacture; forgetting that by the same act it also loses the selling price and hence the profit on them. If, on the contrary, it builds an over-long, or crooked, or otherwise objectionable line, it is in effect fitting itself to produce only an inferior article, which will command a lower price.

40. The force of this parallel is still further and greatly strengthened if we remember that, with much that is similar, there is, in one respect, a momentous and broad distinction between the seller of transportation and the seller of most other commodities. The production or partial production of transportation is, from the necessity of the business, considerably in

excess of the amount sold, and its cost bears a very irregular ratio thereto. Every time, for example, a passenger train starts out, there is "manufactured," so to speak, several hundred passenger trips. If they be not sold, they cannot be stored away on the shelf for the next day's trade, like the remnants of a lot of dry-goods. They are simply wasted and thrown away. It is with the railway much as if tradesmen were compelled to cut a new piece of each kind of goods each day and then throw away the part remaining unsold each night. We should probably under such circumstances observe a conspicuously greater zeal even than now exists for regulating and increasing sales, so as to sell the whole of every piece of goods; whatever price the remnants might bring being so much clear gain.

41. To a greater or less degree, but always to a very important degree, the conditions here suggested exist with respect to every part and kind of railway traffic. We see, therefore, how vital and peculiar is the interest of railways in neglecting no consideration which by ever so little affects its revenue. It is on slight differences of traffic and revenue that the corporation grows rich or poor.

Granting, therefore, that no probable effect upon traffic and revenue which may or can occur from the decisions reached in the original location should be neglected, it will be obvious, as already hinted, that such effects are possible from any one of the following causes:

42. I. THE LENGTH OF THE LINE.—Even slight variations therein are very certain to affect the revenue, as well as the expenses; because all local rates, except by special contract, are nominally fixed by the mile, and all through rates (those shared in by two or more companies) are, without exception, divided according to distance hauled, although not necessarily in exact ratio thereto.

Up to a certain point, therefore, varying in almost every case, the gross revenue certainly, and the net revenue frequently, will be increased by a longer line, as well as the operating expenses. But if the process be carried too far, the traffic will be overbur-

should be fully realized why it is a dangerous and fallacious argument.

47. It is particularly easy to see that the argument is both dangerous and fallacious when there is, or is liable to be, COMPETITION for the traffic, or any part of it, as may be said to be always the case, at least potentially, in the United States. In that case, the only safe rule is, that any considerable difference in haul to the station or in any other convenience to the public will almost wholly destroy the possibility of profit from the traffic to be competed for, even if a portion be secured. For it might be proved by many instances that it requires but a very slight difference in the convenience of access to practically destroy all equality of competition. Except for the very numerous instances of entire neglect of this danger it would hardly seem necessary to speak of the matter at all; for it is evident that, as respects freight traffic, rates must in the long-run be made equal, not simply from station to station, but *from the door of the consignor to the door of the consignee:* in other words, all additional cost for cartage or switching service, and something more as compensation for the trouble (usually a very considerable addition), must be borne by the railway before it is in a position to compete at all. As respects passenger traffic, to a certain class of long-trip travel such minor differences are of less importance, but there is a considerable fraction even of long-trip travel on which they have a recognized and important influence; and devices of all kinds—free omnibuses, more or less open concessions on rates, etc., etc.—are required to counteract what may have been a mere oversight, or bit of indifferent negligence, in the original laying out of the line.

48. Let us imagine an instance which has frequently happened already, and still more frequently will happen: A number of good-sized towns, ten to fifty miles apart, served by two competing lines; one of them coming appreciably nearer to the average centre of population than the other. It is abundantly established by experience that in such a case the favored line can by a moderate amount of effort—which may be counted

on with some certainty—not simply cripple, but almost destroy, its rival's local traffic. For "to him that hath shall be given," with short-haul traffic especially. If one line start with any advantage, that very fact will tend to increase it. It will have a better reputation. It can offer better facilities. The tendency of the traffic of all kinds will be to concentrate itself upon it—just as water always seeks the lowest point, however little lower it may be. Even when a railway can, or thinks it can, count on permanent immunity from competition, it should naturally follow from what has preceded that it is still exceedingly dangerous to put the public to permanent inconvenience and expense under the false idea that "it will cost the Company nothing." Under the best of circumstances there will always be some loss; and the slightest addition to receipts, which might have been secured but is not, would have gone almost in gross to swell the surplus. The slight additional trouble and expense to shippers of *all* freight, and the horse-car and cab fares of passengers, must be paid for sooner or later, in one form or another, by the corporation, if in no other form than in a decrease of traffic. It is not true that nothing which will still leave rates at so much a mile, without immediately affecting them at this or that non-competitive point, is of importance to the Company or has effect upon its revenue.

49. The universal law of trade ultimately obtains with sales of transportation as of everything else. The selling price, the amount sold, and the profit realized on all articles of bargain and sale is ultimately regulated by the quality of the article and the price the consumer is willing and able to pay, and this again is greatly affected even by trifling differences of convenience. We may see this illustrated every day by the difference in price of the same article at fashionable and unfashionable stores; and even when there is but one point at which a certain desired article can be bought, it is a truth universally admitted among business men that minute differences in the price or the quality of the article, or in convenience of access to the place of sale, do have a material influence on the volume of sales, especially in

such articles as are to be sold in great numbers to the general public. That precisely the same argument applies to railways can be denied only by asserting that the patronage of a railway is strictly a matter of necessity—a pure monopoly, except as competed for by another railway; but this, even if it were true of the greater portion of traffic, would certainly not be true at all of the remaining fraction, and it is ordinarily this remaining fraction which alone makes the business of operating the property worth carrying on by the company controlling it: for let us suppose that by systematic negligence at several points in the original laying out of a line a corporation should succeed in affecting its gross yearly revenue so much as one per cent. It would represent certainly five to ten per cent, and very possibly one hundred per cent, of the value of the franchise owned by the corporation, which is usually all they do own, and sometimes a good deal more.

50. If it should seem improbable that any possible error of this kind could so affect revenue, it must be admitted that it is difficult and in fact impossible to produce statistical proof, nor would such proof, even if produced for one locality, be applicable elsewhere; but a striking example, among many, of the natural effect of such reckless neglect may be found at the town of Springfield, Ohio. A dispute about a trifling sum (about $50,000) of town aid to the Atlantic & Great Western Railway, now the New York, Pennsylvania & Ohio Railroad, caused the manager of the road to run the line two or three miles from the town—and this with a slight increase, if anything, in the distance, curvature, and cost. This town has since become, as even then was probable, one of the best shipping points in the State; and, purely in consequence of its inconvenient location, the Atlantic & Great Western secures only an inconsiderable fraction of this traffic, both freight and passenger. Its annual loss of net revenue is, beyond all question, considerably larger than the whole sum originally in dispute; and the disadvantage was so serious that, very recently, arrangements to run into the town over another line were made at heavy cost, while still leaving the line at an immense disadvantage.

51. In this occurrence there is nothing exceptional, even in degree. There is hardly a town of any importance in the United States in which some one of the lines running to it has not done precisely the same thing; so that it is known of all men to be at grave disadvantage in respect to some portion of its natural traffic, whether long-haul and short-haul, and whether passenger and freight. That natural and not unreasonable trait of human nature embodied in the homely proverb, "Give a dog a bad name and hang him," then comes in to intensify this disadvantage. This in turn begets a poverty of means, which begets a poverty of service, which still further increases, and justifies on rational grounds, what may have been in the beginning a rather unreasonable popular prejudice; and the end, in all probability, is a receivership. It will be found, on looking over a list of roads which have failed in this way, that, almost without exception, they are those which merely skirt the edges of the towns which they nominally reach.

52. THE EFFECT ON SHORT-HAUL TRAFFIC of negligence of this kind is, as already hinted, far more serious proportionally than in the case of longer haul—not only because it is far more likely to drive the traffic to other lines, when such exist, but because it is far more likely to have the still further effect of destroying a portion of the potential traffic completely. The longer the journey or the haul, evidently, the less effect will any trifling inconveniences have, and the proportional as well as absolute loss will naturally be less at small towns than large ones—especially than at very large ones where there is a regular and established suburban traffic. Nevertheless no town is so small that the short-haul local traffic is not materially affected by trifling difference of convenience of access. Differences which originate in the subsequent management of the operating department, better cars, time, meals, train employees, surer connections, etc., may have, it has been admitted, relatively much more effect than a mere difference in convenience of access to the station; but the latter, unlike the former, cannot be corrected at any time, and in trips of ten to twenty or fifty or even

one hundred miles, the mere fact that the station is (or is not) convenient for taking and leaving the train is alone enough to have a powerful influence upon the number of such trips, especially in bad weather, but to an important extent in all weather, with the weaker three quarters of the population at least.

53. In very much less degree even the volume of NON-COMPETITIVE FREIGHT SHIPMENTS is similarly affected; besides the fact that it must be assumed, for reasons already stated, that the rates, in the long-run and in some direct or indirect form, will certainly be affected likewise. Sooner or later, in one form or another, the railway will be compelled to make concessions equivalent to paying for the cost and annoyance of cartage on much of its traffic, and lose altogether more than enough to pay for carting the whole of it. There is no clearer moral than this to be drawn from recent railway history.

54. It is also unmistakably evident from recent history that it is impossible to maintain more than a reasonable ratio of disproportion in rates between competitive and non-competitive rates, and between rates on one class of freight and another, even for those classes of freight which do not seem to be affected by any immediate cause tending to have this effect. A clear indication of the existence of this law may be found in Tables 93–5. It is now too well known and generally admitted to require more precise evidence.

55. There is one peculiar phase of the question of RUNNING BY A TOWN TO SAVE DISTANCE which may be more appropriately considered in this connection, as illustrating what has preceded, than in the chapter on Distance.

Let us suppose, to take definite figures, that we have run by a town of ten thousand inhabitants in order to save a deviation of five miles from an air line, involving a loss of a mile or two of distance. As we have already seen in part, and shall more fully see (Chap. VII.), the railway's revenue account suffers heavy loss due to the decreased mileage on most of its local and through business, competitive and non-competitive. *Per contra*, its ex-

pense account is decreased indeed, but in very much less ratio. The probabilities are very strong that there will be a net loss to the revenue. This might well be borne if it meant, as in ordinary cases, simply a reduction of the transportation tax upon the traveller or shipper of freight, but how stands it with the latter? They save, indeed (in the case of local traffic only, but not in the case of through traffic), the two or three cents per mile which the railway loses, owing to its shorter line; but they lose the entire direct cost of cartage or switching charges on their freight and carriage, express or horse-car fares for their own conveyance, besides suffering an annoyance and inconvenience in both cases which they will surely estimate at a good round sum: In money, when by the existence of competition they are able to throw the whole of both of these losses on the railway which seeks their patronage from a distance; in refusal of patronage, except under great concessions or the compulsion of necessity, when through absence of competition they cannot otherwise shift the burden from their own shoulders.

Thus, under any possible conditions, in such a case there is a triple loss: The tax on the public is greater, the receipts of the railway are less per passenger or ton, and the number of passengers or tons is decreased.

56. The net losses might be estimated something in this way, assuming the town, say, to be in Ohio:

LOSS TO THE RAILWAY.

Loss of traffic per head, by being 5 miles instead of 1 from centre of population (say 40 per cent: Table 13), on a natural revenue per head of $10, or $100,000 from the town...........................	$40,000
Loss of revenue, due to one-mile haul on $60,000 of traffic—say three per cent..	1,800
	$41,800
Per contra: saving of expense on same, at 40 per cent on the total expenses, or 26⅔ (40 × ⅔) per cent on the total revenue.............	11,148
Net loss to railway..	$30,652

LOSS TO THE INDIVIDUAL PATRONS.

Expenses of reaching the railway from a point 5 miles off, at 50 cents per passenger or ton, probably about	$25,000
Less saving by reduced payments to the railway, as above	1,800
Net loss to the public	$23,200
Destroyed business, which the public would have been glad to enjoy and pay for, as shown by experience, and which hence would have been worth its cost to them—say one third of the 40 per cent (as above) of $100,000, the rest going to some other line	13,300
Net loss special to the public, per year	$36,500
Net loss special to the railway, per year	30,652
Aggregate loss to the community, per year	$67,152

Which means from the point of view of political economy, and as a plain statement of a fact which would appear in the census statistics, that the CAPITAL of the country and the world is less than it otherwise would be by the capital sum of which $67,152 represents the interest, or (at six per cent) $1,119,200; the whole of which is clear loss, by which NO ONE is benefited.

57. A few hackmen and expressmen are, indeed, diverted from working elsewhere, where they would be true producers, into earning a support by performing what might have been a needless service. It is plain that by this diversion they are, individually, neither benefited nor injured, so that they simply do not enter into the question at all, even from the point of view of political economy. We are not, however, studying political economy, but the art of directing private investment in railway property so as to be profitable, not primarily to the general public, but to the projectors.

Making all allowances for possible errors in the precise figures used above, it represents an immense loss to all parties from running railways by towns without going to them, so far as the traffic of that town alone is concerned, separately considered. There is, however, this further disadvantage to be remembered: if we lengthen the line to reach a town we necessitate that the

whole traffic shall be hauled over this extra distance in order to accommodate the traffic of one town.

58. This raises the general question of the value of distance, for which see Chapter VII. It need only be premised here, what has been in fact already said, that although, as a mere question of political economy, the cost of this extra haul is certainly a net loss, conferring no added value on the service rendered, yet to the revenues of the railway only, considered as a private enterprise for profit, this is by no means the case, since there is always a credit as well as a debit side to the extra haul. It is not uncommon to hear engineers speak and act, indeed, as if the extra haul were a mere burden on the traffic: which would be true enough if railways were charitable institutions built by moneyed philanthropists with the sole purpose of serving the public, and which is always true with respect to that considerable fraction of traffic on which neither the amount nor the distribution of the gross rate is modified by the distance. But, as matters actually stand, it may be rudely stated here that, as the actual cost of such trifling extra haul is very little, the net effect of such deviation for such a purpose is very apt to have a favorable effect, if any (sometimes a decidedly favorable effect), upon the net revenue derived from the entire traffic, independent of that from the particular point for the sake of which the deviation was made, as well as upon the public interest.

For one most important reason why this should be so, see Chapter XXI.

59. It is true that, in so far as the burden upon the general traffic may be increased, there is a tendency to compel the corporation to reduce rates on all traffic to the point which it will bear, instead of making non-competitive rates strictly according to distance; and in urging that a railway will "get something for nothing" out of extra haul, the previous claim (par. 46 *et seq.*) may seem to be contradicted, that even slight burdens on traffic are dangerous; but it is evidently a very different matter for a railway to take measures which make its own charges on all traffic a trifle higher to relieve a part of it from other and

heavier burdens, and to take a course which throws a heavy burden on its own traffic and on its patrons as well, by providing facilities for a lot of outside parties—teamsters, hackmen, and horse-car lines—to extract a percentage forever of the total payments which the traffic has to bear.

60. Admitting, therefore, that differences of location may have a material effect on the revenue, it becomes important to remember that, as we have already seen, as small a difference as one per cent in gross revenue will ordinarily represent from three to six per cent in net revenue, and from six to twelve or fifteen per cent difference in profits to the company proper, after their rental or interest charges have been met, even in the most prosperous companies, and from that up to many hundred per cent in those less favored. Remembering also that errors in the original laying out of the line, unlike errors in subsequent management, are mainly irremediable,—a kind of fixed charge for folly forever,—it will be seen how large is the interest of the company who employ and pay the engineer in avoiding all errors of the kind, and how particularly important it is that no possible difference should be regarded as trifling because it will constitute a trifling part of the total receipts or expenses. It is only a small fraction of that total which "the company" has even the hope of retaining to itself.

When the cream of their traffic, THE PROFIT TRAFFIC, is lost to them, all is lost ; and although it is often true that the business sagacity, or lack of it, with which the enterprise as a whole has been planned will overcome all that the engineer can do to make or mar it, so that the enterprise will succeed or fail in spite of him, yet it is always true that a heavy percentage of the surplus or deficit which alone concerns the company proper—enough, for instance, to make all the difference between a great success and a small success, or a great failure and a small failure—is strictly dependent upon the engineer and upon those, by whatever name they may be called, who decide with him, or for him, the semi-engineering and semi-commercial questions which we have here considered.

61. Therefore, with an end so important before us, any guide is better than none, in order that we may reduce the unavoidable uncertainty to its lowest terms; and under these circumstances a rule which the writer has formulated as a sort of general average to estimate exceptions from is this:

As a minimum: *At the smallest and most inert non-competitive points the annual loss of revenue from placing the station at a distance from town may be taken as equivalent to* 10 *per cent of the revenue naturally originating from such a town, with the station in any given location, for each additional mile that the station is moved off from the centre of the town.*

As a maximum: *At centres of considerable manufacturing or commercial activity, exposed to considerable actual or potential competition, a fair and moderate estimate of the probable loss of revenue from removing the station to a distance will be* 25 *per cent of the revenue naturally originating at such a town, for each additional mile that the station is moved off from the centre of the town; and this is frequently liable, in cases of very sharp competition, to amount to as much as* 50 *per cent of the natural revenue, including all the indirect effects of such disadvantages.*

The first of these estimates the writer has considered to be applicable to such towns as the average of interior Mexico. It is below any class of towns in the United States or Canada, excepting the strictly rural regions consuming and producing little freight shipped by rail. The last is a fair average (varying however within wide extremes) of all the busier towns and cities of the United States.

62. The causes of variations are:

1. Manufacturing and especially mining towns are usually heavy shippers.

2. Towns which are the seats of special industries often make payments to railways out of all proportion to their apparent size and activity.

3. The number of competing lines will greatly affect the proportion tributary to any one line.

And many other like causes. Nothing definite can be pre-

dicted about any one town from any figures in this chapter, but for the average town they are believed to be fair.

They are the result of much comparison of earnings by different lines at large and small towns made by the writer at different times, with an effort to estimate the true cause of their disadvantages ; but to attempt to defend them in detail, except as the volume as a whole may do so, would occupy too much space.

TABLE 13.

ESTIMATED EFFECT ON REVENUE OF REMOVING STATIONS FROM THE CENTRE OF POPULATION OF TOWNS.

Column 1.—Average distance of station from centre of population.

Columns 2 and 4.—Loss per cent of total natural revenue for each additional mile of distance.

Columns 3 and 5.—Remaining per cent of natural revenue left to the company.

The effect of this rule is presented numerically in Table 13, the percentages being in geometrical ratio to each other, so that any number in the column, divided by the first or second or third number above it, gives always the same quotient.

Under this table, the percentage of loss for each additional mile the station is moved away is the same under all circum-

stances, although the absolute loss is much less as the distance increases.

63. The above rule, it should be repeated, is not offered as in any way precise, or perhaps even safe. Such an estimate must always remain, for the most part, a question of judgment. That is the author's judgment. He claims no more solid basis for it than that in many single instances there has been an actual difference in the receipts of competing lines at the same point, or in the receipts of the same line at points at different distances from it, but otherwise very similarly situated, which closely correspond with the figures given.

64. As an example of the working of the above rule, to run two miles off, instead of one, from the centre of a town of 10,000 people would involve as a minimum a loss of 9 per cent of the natural revenue from such a town, or from $1800 to $2700 per year. If the town were an active business place this might easily be several times this amount, and if competition were a factor of the problem it would be very certain to be. If it were a question of running into a town instead of a mile away, the loss would also be liable to be very much greater than the table above indicates, since the stimulating effect of better transportation might change the whole character of the town, besides the natural effect of a given difference of distance. The question would be affected likewise by the character of the termini, etc., etc.

65. As an instance from actual practice, two important Mexican towns, of a population of about 100,000 and 60,000 respectively, and about forty miles apart, with considerable natural traffic between them, were left distant respectively two and a half miles and four and a half miles from the nearest point of the projected line. It was a question whether to bring the railway nearer to the towns, in which case both stations would be half a mile from the centre of population:

If we might assume the above minimum to be correct, the certain loss on all the traffic contributed to the railway by these

towns, and not simply on the traffic between them, would be annually—

$200,000 × 0 19	=	$38,000
120,000 × 0.344	=	41,280
Total ($217 per day)		$79,280

For Mexican towns, in their present condition of imperfect material development, this is possibly large enough; but for American towns of equal size and importance it would almost certainly be far too low. If it were to be considered as solely affecting the passenger traffic, and of such traffic only that existing between the two towns, it would amount to the loss of sixty-five to seventy round trips per day, and this in the United States, between two active business points at that distance from each other, would be far from an exaggerated estimate.

It would in such a case, however, be extremely erroneous to consider only the traffic between the two points. All the traffic originating or terminating at each point is more or less affected, the importance of the effect decreasing with the length of the haul. The freight traffic will also be materially affected, in some slight degree in volume, and a large proportion of it in average rates, for reasons already pointed out, the chief of which is that the railway sooner or later pays for the cartage.

66. Yet all these arguments, like almost everything else connected with the laws of trade, require to be applied with great caution, and are subject to many exceptions, such as these which follow:

Towns will in many cases move to the railway, if the railway does not come to the town, with ultimate benefit to all parties concerned. This is especially common and probable in the United States, but it is more or less true everywhere. In proportion as the population and traffic may be expected to increase, the importance of accommodating the line to that which already exists becomes less and less.

Even in a region tolerably well settled, but heretofore undeveloped by railways, or imperfectly developed, a bold neglect of

existing centres, especially those of minor importance, will be exceedingly apt to bring them sooner or later to the railway instead of losing the railway their traffic; and this will be in some cases, where other lines are not likely to compete, the more apt to follow the more completely such points are left out in the cold.

Especially when, by taking a central line between two subordinate centres of this kind, about as much will be gained from the one as lost from the other, the ultimate effect will probably be to build up a new town between both, affording new traffic, while still retaining a good proportion of that which remains at each of the old centres, and could have been fully secured from one of them only by wholly neglecting the other; thus substantially increasing the aggregate traffic of the line.

This amounts to saying that in seeking to pass through the centre of the population, as in determining the centre of gravity, we cannot always consider one body alone, but must consider several as constituting one composite entity.

67. So, too, it is easily possible, in laying out branch lines or the parts or links of extended systems, to be so over-anxious to secure some trifling advantages of local traffic as to seriously burden and cripple other and much more important interests, or perhaps lay the line open in the future to destructive competition.

These various possibilities—*con* as well as *pro*—are very frequently the most important of those which fix or should fix the location of a line. Especially in easy country it may almost be said to be the rule that these will be important enough to overrule engineering disadvantages of considerable moment, the extent of which latter, therefore, it will often be waste of time to consider; and even in the most difficult country it will usually require marked and decided engineering disadvantages to justly overbalance any considerable advantages as respects probable traffic and revenue.

68. The question of the LOCATION OF TERMINI, and its effect upon traffic, is really closely allied to, and in fact a part of the

general question of how near to bring the line to towns, which we have just been discussing. Nevertheless, from the fact that the terminal towns are usually by far the most important on the line and likewise the most costly points to approach closely, sound business judgment is violated more frequently and more dangerously at such points than at points along the line. Had it not so often happened that lines which have expended millions for the construction of long lines to a certain place have then begrudged or failed to raise the necessary additional percentage to carry their line into it, contenting themselves with hanging on to the skirts of the town somewhere, where they can be reached by horse-cars or hacks and drays, it would seem incredible that business corporations could so frequently commit an act of folly which can fairly be paralleled with that of building a long bridge and erecting every span but one—assuming, on account of some difficulty with foundations, or what not, that a ferry would be good enough for that, because it would be "such a little one." The lines which do or have pursued this course will be found to be those which figure most prominently in the list of bankrupt corporations; and the evidence of that fact is so patent to any one who will take a list of such and study it over, that it is needless to add more to what has been already said than to note the great sums which successful properties spend in reaching the heart of great cities to remedy former errors.

69. In England hundreds of millions have been expended for this purpose, and tens of millions at the smaller towns alone. In America we are far more backward than the best interest of the properties requires: but many such works have been recently carried through, one example of which is the new entrance of the Pennsylvania Railroad into the city of Philadelphia; while at New York, Boston, St. Louis, and other cities similar improvements have been made or are being projected on a lavish scale. Certainly it has never been questioned that the Philadelphia terminus was an expedient investment, and we may be sure that it was not undertaken with any other view by the management of the company. It was executed almost wholly for the local con-

venience of Philadelphia, and consisted in carrying in the company's tracks on an elevated structure to a point very near to the centre of the city. It was, moreover, an expenditure to which the company was not driven by competition, except as to a small part of their traffic, for they had good facilities for both freight and passengers; facilities as conveniently accessible as they well could be by horse-cars—that ever-ready excuse for neglecting to bring railway-stations into the centre of population. Some increase of space was indeed desirable, but it might have been secured much more cheaply in other ways, had the company deemed it expedient.

The Philadelphia improvement cost about $4,590,000, of which about half was for land only; or about $5 per head of the population concerned, the interest on which at five per cent is about $225,000 per annum, or twenty-five cents for each man, woman, and child of the population—a sum which should be largely increased, perhaps doubled, for the indirect loss on investments already made, and from operating expenses for hauling the whole traffic into and out of the new station, to which the system of roads centring there had not been originally adapted.

It is to be presumed, of course, that the value of this improvement to the corporation is expected to be considerably more than this. Nor does such expectation seem unreasonable; for, independent of all necessity for competition, experience at other points proves that it would be a paying investment, from its direct and indirect effect to encourage new traffic.

In the company's report for 1881 it was stated—

> "The cost of this work is already having a marked effect on the development of local traffic; and it is believed that, in addition to its great value to through and competitive business, it will in a few years, by its promotion of suburban trains reaching the park and other portions of the city, and its stimulus to the traffic before referred to, fully realize all that was contemplated at the time of its original construction."

At the time of this report there were some two hundred passenger trains into and out of Broad Street Station daily. There are now about fifty per cent more.

70. At New York a costly improvement was carried through at the joint expense of the city and the New York Central and Hudson River Railroad, costing some $8,000,000, in order to permanently insure the running of fast trains to the Grand Central Station at Forty-second Street, which will probably hereafter be the heart of the population patronizing the railway, although for the present it is rather far up-town. The then existing passenger station at Twenty-eighth Street was abandoned, in part on account of the difficulties and expense involved in securing room at that point for the immense traffic to be handled, and in carrying the line to it, but in part because the point selected was deemed to be so near the future centre of the city. An additional passenger station (mainly for suburban trains) is still maintained on the west side, at Thirty-second Street, as are also freight stations farther down-town on both the east and west side, to and from which cars are hauled by horses.

71. At St. Louis, a union depot for all the railways centring there was built in connection with the great St. Louis Bridge, the whole costing some $7,000,000; while there is hardly a city of any importance where smaller improvements of the kind are not projected by some one of the lines reaching it, at a largely increased cost over what would have been originally necessary;—without considering in this statement the heavy losses of traffic through the dubious early years of the company's history which have enforced such improvements. On the other hand, there is no instance on record where adequate terminal facilities once acquired have been abandoned for others more distant and less valuable, because the market value of the property was greater than its productive value in the hands of the company.

72. To apply the same ratio of expenditure as is incurred at the larger cities to smaller places might not in many cases be safe for these reasons:

First. The average receipts per head of population increase very much faster than the population. (See Chap. XXI., and the various tables giving revenue per head of population.)

Secondly. At very large cities like New York, Philadelphia, Chicago, and Boston, the distinctly suburban traffic, making daily trips at commutation rates, is a large element, which especially requires the best attainable terminal facilities and the largest possible saving of time.

Table 14 gives some idea—in part, it must be confessed, a deceptive and imperfect one—as to how large a part these various works constitute of the total cost of railways of the first class, and how small an element is the mere construction to sub-grade between stations. See also Chapter XXVI., on "Terminals."

Table 14.

Proportion and Amount of the Various Items of Cost of Road and Equipment.

New York Central & Hudson River Railroad, 1885, 953 miles; amount of track, 2.85 times length of line; and in less detail for Pennsylvania Railroad, 1257 miles.

New York Central & Hudson River.

Items.	Per Mile.	Per Cent.
Grading and masonry	$22,000	18.9
Bridge	3,030	2.6
Superstructure	32,500	27.9
Stations, etc.	15,400	13.3
Land and land-damages	15,740	13.6
Locomotives	6,630	5.7
Passenger cars	1,617	1.4
Freight cars	15,830	13.6
Engineering	3,160	2.7
Floating Equipment	293	.3
Total	$116,200	100.0
Stock	93,800	....
Bonds	59,000	....

Pennsylvania.

Items.	Per Mile.	Per Cent.
Construction	$30,400	50.7
Equipment	19,300	32.3
Real estate and telegraph	10,130	17.0
Total	$59,830	100.0
Stock	$75,300	....
Bonds	53,500	....

The Pennsylvania owns enormous amounts of the securities of controlled roads, represented by its securities. Its policy has been to defray expenses out of earnings rather than increase capital account.

The small proportion which the bare cost of laying down the track bears to the total investment, on lines of importance, is clear from the above.

Thirdly. At almost all points in the United States the probabilities of future growth must be remembered, which will sometimes, as at New York, bring a point which is, for the time being,

considerably outside of the centre of population into the very heart of it.

Nevertheless, no town is so small that the considerations advanced are not more or less applicable to it, and the usual law of development, when topographical impediments do not forbid it, is that the town spreads equally in all directions, its centre of gravity remaining unchanged, as in the case of London, and measurably of Chicago, Philadelphia, and other cities; in which case the disadvantages of having a terminus at a distance from that centre do not decrease with time, but increase in direct ratio to the population.

73. Although the impossible task of definite technical analysis of the revenue considerations here discussed has been passed by, it is hoped that enough has been said to impress upon the minds of engineers and projectors that they are entitled to great, if somewhat indeterminate, weight, and that it is unsafe for any engineer to enter upon the work of laying out a railway with no more thought of its financial future than a vague idea that the passenger revenue is obtained by selling tickets, and the freight revenue is measured by the sum of the way-bills, and that neither is any concern of his; his duty being simply to get the shortest, cheapest, and straightest line,—the phrase has almost hardened into a formula,—and that when he has gotten it he has done his whole duty. It may be that he has, but it does not follow; and the chances are good that he will have not only completely failed to do it, but will have involved the projectors in certain ruin; because, although the amount by which the revenue can be modified by differences of location, or even by differences in the subsequent management, is, as a rule, only a small percentage of the aggregate revenue, yet it is this small percentage alone in which the original projectors have a property interest; that portion of the revenue which goes to pay fixed charges and operating expenses being in no sense theirs.

The strength of the argument for neglecting no effort to reach all possible sources of traffic is greatly strengthened by the considerations which it seemed more appropriate to discuss in

Chapter XXI., but which have a very direct bearing on the subject-matter of this chapter.

74. That the effect of comparatively slight causes to influence revenue has not been exaggerated, may perhaps be proved, as effectually as in any way, by a trivial incident which the writer knows to be authentic:

A certain railway, for competitive reasons, determined that some marked improvement in its eating stations must be made to meet the competition of dining-cars on a rival line. The proprietor of one of these establishments, therefore, was instructed to make certain decided improvements in the appointments of his table, and in the character and quality of the viands provided, at the expense of the company, and to send in his bills from time to time for this additional expenditure. The bills not coming in, although the desired betterments had been (with some reluctance) made, and with results very gratifying to the company, the proprietor was again requested to send in his bills; when it appeared, on inquiry as to each item in succession for which he had been specifically instructed to increase his expenditure at the expense of the company, that the proprietor was "satisfied that it paid him," or that it was "no more than he ought to do," or that he was "well enough contented as it was" —in short, that he had no bills to present.

Such an incident, the details of which were precisely as stated, must be admitted to be an extraordinary instance of the power of conscience in a class who are not often given credit for having any, but it is also a proof that great direct advantages to the proprietor, as well as indirect advantages to the company, must have resulted. To fully appreciate its bearing upon those semi-technical questions which depend more or less on the peculiarities of human nature, two additional facts must be remembered. On the one hand—

1. A large fraction of the passengers have but slight reason to choose between one or another railway before beginning their journey; while, on the other hand,

2. The journey once entered on, they have no choice what-

ever as to where to take their meals, but to take such meals as are set before them at the appointed stopping-places, or go hungry. The railway restaurant business is pre-eminently non-competitive.

If, therefore, a trifling improvement in meals, which had never been really bad, could so materially affect the non-competitive business of a railway restaurant, what is the probable effect of the same and other slight causes on the traffic—especially on the receipts from that considerable class who travel a great deal by rail, but hardly make a really necessary trip more than two or three times in a lifetime?

With this attempt to solve by a parable an essentially indeterminate problem, we pass to those branches of our subject which are often of less real importance, but which admit of more definite and technical treatment, and which, perhaps for that reason, are, not unnaturally, too often the only ones considered by members of a definite and technical profession.

CHAPTER IV.

THE PROBABLE VOLUME OF TRAFFIC, AND LAW OF GROWTH THEREIN.

75. It having been once determined that a railway is to be built at all between any two points, with the consequent *prima-facie* corollary that, excepting when and as reasons to the contrary appear, it is to be the cheapest line over which trains can be run with due safety and speed, the probable nature and volume of the future traffic becomes the vital question ; for both the revenue and the operating expenses will vary in close ratio therewith, and only to increase the one or diminish the other are we justified in expending more money than proper security in handling trains requires. The more the traffic of a railway the larger the pecuniary saving from a given betterment in the rate and distribution of gradients, curvature, or distance—and the more, consequently, the justifiable expenditure to effect it ; the criterion being : Will a certain betterment, which is not an essential for the safe passage of trains, save the company more per year in operating expenses (or add more to the revenue, in the limited class of problems in which that question comes in) than it will add to fixed charges by the capital expended to effect it ? If it will, the expenditure and betterment should be made ; if it will not, it should not be made.

76. To determine the probable volume of traffic with exactness is of course impossible ; nor is it, fortunately, particularly important to do so, if we make a reasonably close approximation ; for the reason elsewhere discussed, that, with a judiciously located line, the saving by adopting a poorer line than one naturally adapted to the topography is ordinarily not so great that any

probable deficiency in the estimate of traffic would permit of it; while, on the other hand, the cost of defying the natural topographical conditions is ordinarily too great for any probable excess in the estimate of traffic to permit of it wrongly. In other words, the danger lies in having no criterion, or in a false perspective as to the relative importance of various ends, or in purely arbitrary decisions based on no investigation whatever, rather than in a certain percentage of error in our criterion.

All that we need to do, therefore,—all that will have any important bearing on our action, as experience will soon teach, —is to bring reasonably near to each other the maximum and minimum probabilities,—"the limits of error in either direction, somewhere within which lies the truth and anywhere outside of which lies a certainty of error." This there is ordinarily no difficulty in doing.

77. In a rude way it can be done at once by any one at all familiar with railroad work. We know at once whether a line is more likely to have a light local traffic or a trunk-line traffic. It is but a step further to determine with very approximate exactness that a line will have somewhat more traffic than this or that or the other line near it, or similarly situated in other regions, and less traffic than as many others; from which the establishment of a mean for the immediate traffic and its future growth is, with some knowledge of railroad business, a simple matter.

78. The greatest difficulty in making such estimates is ordinarily the fact that to make them it is essential to estimate and allow for the probable future growth of traffic, since it is rarely the case that a railway, especially in the United States, is built simply and only to accommodate the traffic "in sight," as miners say. On the contrary, it has been and will continue to be frequently the case that the railway is relied upon not only to accommodate but to create a great part or the whole of the traffic for which it is built. Even when the population of the region traversed cannot, as it can in most parts of the United States, be expected to rapidly increase, experience has shown that if the surrounding territory has heretofore been but scantily

provided with railway facilities, (1) the traffic of the first few years will be but a small proportion of what would normally be expected from a similar population elsewhere, and (2) that it

TABLE 14½.

EARNINGS PER HEAD OF POPULATION AND PER MILE OF THE RAILWAYS OF THE STATE OF IOWA.

YEAR.	MILES OF ROAD.		POPULATION.		GROSS EARNINGS.		
	Total.	Increase.	Actual or Estimated. 1 = 1000.	Per Mile of Road.	Totals.	Per Mile Road.	Per Head Population.
1862	626	....	778.	1,243	$1,109,346	$1,772	$1.42
1863	653	27	830.	1,271	1.570,546	2,405	1.89
1864	727	74	882.	1,212	2,553,699	3.512	2.89
1865	847	120	934.	1.103	3.871,783	4,572	4.14
1866	1,060	213	† 986.	930	4,118,006	3,884	4.12
1867	1,228	168	† 1,038.	838	5,867,501	4,778	5.65
1868	1.448	220	† 1,040.	734	8,024,931	5.541	7.36
1869	2,081	533	† 1.142.	550	10.409.950	5.002	9.12
1870	2,683	602	* 1.194.320	445	11,932,352	4.447	10.00
1871	3.160	477	† 1,231.600	389	....	.. ..	.....
1872	3,643	483	† 1,270.100	349	....	......	.....
1873	3.728	85	† 1.309.800	352	....	......	.....
1874	3.765	37	† 1,350.700	359	....	......	.....
1875	3.850	85	* 1.393.000	362	... .	......	.....
1876	3,939	89	† 1,436 500	365	....	......	... .
1877	4.134	195	† 1,481.400	360	....	......	.....
1878	4.157	23	† 1,527.700	368	(24.550,000)	5.903	16.08
1879	4.396	239	† 1.575.400	359	(24.500.000)	5.587	15 54
1880	4,977	581	* 1,624.615	327	(27,250,000)	5,491	16.80
1881	5,426	449	† 1,675.400	309	28,452,181	5,084	16.98
1882	6,337	911	† 1,727.700	272	32,023.966	5,607	18.54
1883	7,015	678	† 1,781.700	258	34,433,355	5,386	19.35
1884	7.249	234	† 1.837.400	253	35,735,272	5,481	19.46

* Actual. † Estimated.

The tendency of earnings to increase about as the square of the population tied together by convenient means of transportation, discussed in detail in Chapter XXI., is very conspicuous in this and the following table.

may be expected for the first few years to have an abnormally rapid growth. Table 14½ shows this clearly. Even in a comparatively densely populated State like Massachusetts, or in a country like England, which are neither growing rapidly in population nor ill provided with existing facilities, experience has shown (Tables 15 and 16) that the rate of growth is rapid enough (from 5 to 8 per cent per annum, as an average) to

TABLE 15.

EARNINGS PER HEAD OF POPULATION AND PER MILE OF ROAD OF THE RAILWAYS OF MASSACHUSETTS.

YEAR.	MILES OF ROAD.		POPULATION.		GROSS EARNINGS.		
	Total.	Per cent. in Mass.	Actual and Estimated. 1 = 1000.	Per Mile Road.	Total (Thousands).	Per Mile Road.	Per Head Population.
1845	463	97	837.	1,885	$2,895	$6,250	$3.35
46	622	96	882.	1,542	3,642	5,850	4.23
47	715	95	909.	1,336	4,965	6,950	5.19
48	787	94	937.	1,265	5,406	6,890	5.43
49	945	93	965.	1,096	5,742	6,080	5.54
1850	1,092	92	994.514	992	6,420	5,890	5.94
51	1,142	91	1,016.	978	6,600	5.770	5.91
52	1,150	90	1,038.	1,003	6,886	5,990	5.95
53	1,164	89	1,060.	1,013	7,977	6,870	6.70
54	1,194	88	1,083.	1,024	8,696	7,300	7.04
1855	1,281	87	1,107.	972	9,077	7,090	7.11
56	1,325	86	1,130.	960	9,750	7,370	7.42
57	1,351	85	1,155.	972	9,094	7,360	6.69
58	1,380	84	1,180.	973	8,597	6,230	6.12
59	1,380	83	1,205.	993	9,771	7,080	6.75
1860	1,371	82	1,231.066	1,033	9,936	7,260	6.63
61	1,366	81	1,252.	1,063	8,669	6,340	5.62
62	1,386	81	1,273.	1,080	9,655	6,960	6.09
63	1,475	82	1,295.	1,042	11,711	7,920	7.21
64	1,486	83	1,317.	1,070	14,981	10,100	9.78
1865	1,500	83	1,340.	1,108	17,459	11,660	11.04
66	1,550	84	1,362.	1,088	19,242	12,430	12.16
67	1,612	84	1,385.	1,076	19,444	12,100	12.17
68	1,749	85	1,409.	1,023	20,788	11,920	12.60
69	1,979	85	1,433.	930	22,495	11,380	13.35
1870	......	1,475	1,457.351	988	......	13,220	13.40
71	2,098	1,601	1,487.	930	27,186	12,950	13.94
72	2,194	1,658	1,517.	914	30,879	14,080	14.30
73	2,365	1,735	1,548.	962	34,930	14,800	15.38
74	2,418	1,783	1,580.	887	34,000	14,070	15.88
1875	2,459	1,817	1,612.	895	31,495	12,820	14.35
76	2,479	1,837	1,645.	896	29,856	12,070	13.48
77	2,496	1,855	1,678.	903	28,932	11,620	12.77
78	2,492	1,850	1,713	927	28,003	11,250	12.15
79	2,626	1,862	1,747.	941	29,153	11,100	11.80
1880	2,667	1,893	1,783.085	945	33,662	12,640	13.38
81	2,755	1,928	1,820.	944	35,936	13,070	13.85
82	2,778	1,949	1,859.	955	39,094	14,100	14.78
83	2,783	1,953	1,897.	974	41,636	15,010	15.40
84	2,852	1,974	1,937.	982	41,457	14,560	14.86

The actual mileage in the State limits is not given previously to 1870, and an assumed percentage has been used to determine the population and earnings per mile of road. From 1870 to 1884 the earnings per head are computed by assuming that the average earnings per mile of road were no greater inside than outside the State limits, which is certainly incorrect, and on an average will probably make the earnings per head *ten to fifteen per cent too small.* From 1861 to 1870 inclusive the total earnings within

constitute an element which might be legitimately considered in laying out a new line. The table embodying this English experience is very instructive, as indicating a minimum of growth under settled conditions which no large section of this country is likely to fall below for many decades.

In all but the rarest instances, it would be absurd to claim that no allowance should be made for future growth of traffic, and often it should be a very large one. Nevertheless, while, theoretically, large allowances for this future traffic are almost

TABLE 16.

GROWTH OF ENGLISH RAILWAYS AND RAILWAY TRAFFIC.

YEAR.	MILES.			CAPITAL.		No. of Passengers. Millions.
	Double or more.	Single.	Total.	Total. 1 = $1,000,000.	Per Mile. 1 = $1000.	
1855	6,153	2,182	8,335	1446.	173.4	118.6
1860	6,690	3,743	10.433	1692.	164.0	163.4
1865	7,711	6,143	13,854	2213.	166.6	251.9
1870	8,338	7,038	15,376	2574.	165.7	336.5
1875	8,898	7,760	16,658	3061.	183.8	507.0
1880	9,803	8,130	17,933	3537.	197.2	603.9
1884	10,239	8,625	18,864	3892.	206.1	695.0

YEAR.	RECEIPTS.					Per Cent Operating Expenses.	Per Cent. Net Receipts to Capital.
	Total. Millions.	Per Mile of Road.	Per Train Mile.	Per Cent from—			
				Pass.	Freight.		
	$	$	cts.				
1855	104.6	12,530	140.6	49.7	50.3	....	....
1860	134.8	12,930	131.5	47.1	50.9	47	4.19
1865	174.4	13,120	125.0	46.2	53.8	48	4.11
1870	210.8	13,570	124.4	42.8	53.5	48	4.41
1875	286.3	17,200	136.5	42.0	54.3	54	4.45
1880	306.0	17,040	127.2	41.5	54.6	51	4.38
1884	328.8	17,440	121.3	42.6	53.4	53	4.16

Compiled from the Board of Trade returns.

the State were given separately. Previously to 1861, the total earnings divided by the population of the State was multiplied by the assumed per cent of mileage within the State limits for the earnings per head. The compilation for the years preceding 1871 was abstracted from an old volume of the *Railway Times*.

See also Tables 21 to 26, 83, and various others for indications as to growth of traffic.

always justifiable, it is for practical reasons so exceedingly dangerous as to amount to absolute folly for an average American corporation, even of the more prosperous kind, to look ahead for more than from three to—at most—ten years for the "rapidly increasing traffic" which is to justify an increase of present expenditure over what the prospects of the present and the immediate future will justify.

79. Let us see why this is so. The theory of the subject is simple: In Table 18 is given the present value or present justifiable expenditure to save $1 (or one unit of any other value) at the end of any given period at any given rate of interest; that is to say, the sum which, if placed at compound interest now, will produce $1 at the end of the specified period. This fact given, it logically follows, that if the value of a given betterment for a given immediate traffic be $1, the present value of the same betterment for an equal traffic which is to exist only in the future will be that sum which at compound interest will produce $1 when the assumed traffic comes to exist. If, for example, we expect the traffic to double in ten years, we may spend for a betterment worth $1 to the present traffic, $1 + the sum which will produce $1 at the end of ten years, which latter is at 7 per cent (Table 18) 50.8 cents; so that under these conditions (which would apply to most new American lines) we should be warranted in spending 50.8 per cent more money to effect given betterments than we would for the traffic "in sight."

TABLE 17.

VALUE OF $1 PLACED AT COMPOUND INTEREST FOR A TERM OF YEARS.

Years.	With Interest at—							
	3 per cent.	3¼ per cent.	3½ per cent.	4 per cent.	5 per cent.	6 per cent.	8 per cent.	10 per cent.
1	1.03	1.03	1.03	1.04	1.05	1.06	1.08	1.10
2	1.06	1.06	1.07	1.08	1.10	1.12	1.17	1.21
3	1.09	1.10	1.11	1.12	1.16	1.19	1.26	1.33
4	1.13	1.14	1.15	1.17	1.22	1.26	1.36	1.46
5	1.16	1.18	1.19	1.22	1.28	1.34	1.47	1.61
6	1.19	1.22	1.23	1.27	1.34	1.42	1.59	1.77
7	1.23	1.26	1.27	1.32	1.41	1.50	1.71	1.95
8	1.27	1.30	1.32	1.37	1.48	1.59	1.85	2.14
9	1.30	1.34	1.36	1.42	1.55	1.69	2.00	2.36
10	1.34	1.38	1.41	1.48	1.63	1.79	2.16	2.59

TABLE 1

VALUE OF $1 PLACED AT [illegible] A TERM OF YEARS.

Formula: $S = (1 + r)^n$, in which r = rate of interest, n = number of years, and S = amount of $1 at compound interest.

TABLE 20.

SHOWING THE JUSTIFIABLE PRESENT EXPENDITURE TO SAVE $1 PER ANNUM FOR VARIOUS TERMS OF YEARS AT VARIOUS RATES PER CENT FOR CAPITAL.

TERM OF YEARS.	JUSTIFIABLE PRESENT EXPENDITURE WITH INTEREST AT—							
	3 per cent.	4 per cent.	5 per cent.	6 per cent.	7 per cent.	8 per cent.	9 per cent.	10 per cent.
1	$0.97	$0.96	$0.95	$0.94	$0.93	$0.93	$0.92	$0.91
2	1.91	1.89	1.86	1.83	1.81	1.78	1.76	1.74
3	2.83	2.78	2.72	2.67	2.62	2.58	2.53	2.49
4	3.72	3.63	3.55	3.47	3.39	3.31	3.24	3.17
5	4.58	4.45	4.33	4.21	4.10	3.99	3.89	3.79
6	5.42	5.24	5.08	4.92	4.77	4.62	4.49	4.36
7	6.23	6.00	5.79	5.58	5.39	5.21	5.03	4.87
8	7.02	6.73	6.46	6.21	5.97	5.75	5.53	5.34
9	7.79	7.44	7.11	6.80	6.52	6.25	6.00	5.76
10	8.53	8.11	7.72	7.36	7.02	6.71	6.42	6.14
11	9.25	8.76	8.31	7.89	7.50	7.14	6.81	6.50
12	9.95	9.39	8.86	8.38	7.94	7.54	7.16	6.81
13	10.64	9.99	9.39	8.85	8.36	7.90	7.49	7.10
14	11.30	10.56	9.90	9.30	8.75	8.24	7.79	7.37
15	11.94	11.12	10.38	9.71	9.11	8.56	8.06	7.61
16	12.56	11.65	10.84	10.11	9.45	8.85	8.31	7.82
17	13.17	12.17	11.27	10.48	9.76	9.12	8.54	8.02
18	13.75	12.66	11.69	10.83	10.06	9.37	8.76	8.20
19	14.32	13.13	12.09	11.16	10.34	9.60	8.95	8.37
20	14.88	13.59	12.46	11.47	10.59	9.82	9.13	8.51

TABLE 20.—*Continued.*

This table gives simply the capital sum which will—

(1) Return \$1 per annum in interest during the given term; and,

(2) Return an additional sum in interest each year which, placed at compound interest at the same rate, will extinguish the principal at the end of the given term.

At 10 per cent for capital it is worth spending but twice as much to ensure a saving of \$1 per annum for ever as to ensure it for 7 years only. At the much higher rates which people often wish to be assured of before spending money in new enterprises it is worth practically nothing to save money more than 6 or 8 years ahead.

80. All this is undeniably correct in theory, except, indeed, that it understates the case; for we might enter into further mathematical subtleties, and prove that if the ratio of growth of traffic is greater than the rate of interest on capital, the present justifiable expenditure to provide for such increase of traffic is infinite. But this, while an excellent exercise for the student, we shall not attempt to do; confining ourselves instead to the more profitable work of pointing out the reasons why, with any ordinary corporation, all such speculations are wholly delusive, so that even the indications of Table 18 are of value only as fixing a maximum which should never be exceeded.

81. The first and most vital reason is that, while it may be taken as a practical certainty that the traffic of any ordinary railway not only will grow, but that it will grow at an average rate of something like 5 to 8 per cent per annum east of the Alleghenies, and 7 to 10 or 15 or even 20 per cent per year west of there, yet that the rate of this growth of traffic is excessively variable and uncertain—liable to cease altogether at any time for many years, and at periods when it is particularly inconvenient to put interest on discounted expectancies.

For this cause alone it is in general inexpedient to look forward more than at most five years for traffic to justify an increase of immediate expenditure; and when, as is of course more likely to be the case, a new project is floating upon the top of a "boom" or upward wave in the tide of business, it is unsafe to look ahead more than two or three years. It is at such times especially to be remembered that the wave may begin to flow backward at any time, and that even if it do not, the line is built with borrowed capital, and that it is difficult for the average financier to borrow large sums on future expectancies; nor can he in any case borrow $2000 per mile as cheaply as $1000 per mile. Borrowed, however, the money must be if the first supply gives out, or the whole investment of the original company will probably be lost; and the instances are rare in which any large proportion of the entire capital has been positively secured before the surveys are substantially complete and construction in progress.

82. A sequence of events which has been again and again repeated is that the company shall enter upon the work with vague visions of boundless prosperity, and look with certainty to securing "all the money they need;" shall encourage their engineer in a costly style of construction which, with the natural preference of an engineer for massive, durable, and stately works, he is all too ready to adopt; and finally, often within a ridiculously short time of the period of their brightest hopes, be left stranded by the ebb-tide of speculation, a complete and helpless financial wreck.

83. Finally, there is another and still stronger reason why the growth of traffic should not be counted on for many years ahead in designing the works. It is usually a simple matter to so design large parts of the line, including most of the more expensive works, that their construction may be postponed until a more convenient season—a possibility so important that it is separately discussed hereafter (Chap. XXIII.). By so doing we at least make sure of keeping the capital account at a minimum and of (usually) retaining the line in the hands of the original company; while, when all causes are considered, the loss from postponing the execution of all more costly work which can be postponed will not be very great, even if one's brightest dreams are realized—which will rarely be the case.

84. We may conclude, therefore, that although a railway corporation which has in truth as well as in imagination unlimited means; which is able to look ahead with certainty for a long period of years; which is able without doubt to tide over long periods of depression without danger to its stability, and which has no anxiety to realize present profit, or even avoid present losses, on investments which will be ultimately profitable;—although such a corporation may legitimately make a large increase in its investments for the sake of a traffic which is still in the distant future, yet that no ordinary corporation can afford to look ahead more than two to five years for the traffic to pay interests on increased investments, and that even in that case they take much risk in doing so. Traffic should therefore,

TABLE 21.

STATISTICS OF THE RAILWAYS OF THE UNITED STATES BY SECTIONS—1881, 1885.

Group of States.	Length of Railways.								Stock and Bonds.			Results of Operation. 1 = $1,000,000.			
	Miles.	Sid-ings, etc.	Steel Rail.	Aver-age Worked	Per Mile of Railroad.		Per cent of		Total. 1 = $1,-000,000.	Amount per—		Reve-nue.	Oper-ating Exp.	Net Reve-nue.	Per cent Oper-ating Exp.
					Sq. miles.	Popu-lation	Sid-ings.	Steel Rail.		Mile R'y.	Head Pop'n.				
1881.															
New England......	6,161	2,308	3,213	6,261	11.0	650	37.4	52.0	325.26	$52,700	$81	52.88	36.97	15.92	70.0
Middle....	15,984	10,787	12,127	16,213	8.60	775	67.3	76.0	1704.74	106,600	138	228.40	143.54	84.86	62.9
Southern...........	18,004	1,961	5,688	14,002	25.7	681	10.9	31.6	722.12	40,200	59	63.74	41.50	22.24	65.0
N. W. Central......	44,702	9,620	20,960	42,465	9.90	351	21.3	46.9	2486.71	55,600	157	276.92	168.98	107.94	60.9
Far W. and S. W...	13,524	960	4,665	10,510	61.9	310	7.1	34.5	634.13	46,900	151	67.47	40.68	26.82	60 2
Pacific.............	5,948	574	2,411	5,034	181.0	261	9.6	40.5	441.74	74,300	285	35.91	17.90	18.88	49.9
Total U. S.....	104,325	26,211	49,063	94,486	29.0	481	25.1	47.1	6314.70	$60,530	$126	725.32	449.57	276.65	61.9
1885.															
New England......	6,412	2,909	5,634	6,475	10.6	671	45.2	87.8	385.49	$60,000	$90	56.85	39.55	17.30	69.6
Middle.............	17,990	12,266	20,470	17,794	....	714	68.1	114.0	2277.15	126,400	177	206.80	134.21	72.59	65.0
No. Central........	40,624	9,799	31,220	42,199	.. .	305	24.2	77.0	2276.51	56,100	183	244.93	164.76	80.17	67.7
So. Atlantic.......	11,501	1,264	7,743	10,306	....	618	11.0	67.2	475.19	41,300	67	36.09	24.72	11.37	68.5
Gulf and Miss......	9,688	1,195	6,584	9,294	....	751	12.4	68.0	539.05	55,700	73⅓	40.34	26.86	13.48	66.6
So. West...........	21,381	3,180	13,640	19,541	....	355	14.9	63.8	1123.77	52,700	148	91.22	58.14	33.08	63.8
No. West...........	12,850	1,516	8,202	11,666	...	473	11.8	63.1	752.17	58,600	124	55.90	32.10	23.80	57.4
Pacific.............	7,283	739	4,609	5,835	....	248	10.2	63.3	509.96	65,200	278	33.18	18.48	14.70	55.8
Total U. S.....	127,729	32,868	98,102	123,110	23.6	476	25.8	76.8	8339.29	$65,300	$148	765.31	498.87	266.49	65.2

TABLE 21.—*Continued.*

STATISTICS OF THE RAILWAYS OF THE UNITED STATES BY SECTIONS—1881, 1885.

Group of States.	Paid to Owners. 1 = $1,000,000.		Amount of Revenue received per—				Equipment.						
			Mile of Railroad.		Head of Population.		Number of—				Number per Mile.		Gross Revenue per Eng. 1 = $1,000.
	Bonds.	Stock.	Gross.	Net.	Gross.	Net.	Engines.	Pass. Cars.	Bagg'e Cars.	Freight Cars.	Engines.	Freight Cars.	
1881.													
New England......	6.13	8.39	$8,420	2,530	$13.10	3.96	1,633	2,111	745	35,233	.26	5.7	32.3
Middle...........	43.30	33.31	14,000	5,220	18.50	6.80	6,045	5,585	1,236	262,942	.373	16.5	37.8
Southern..........	11.15	3.59	4,550	1,590	5.20	1.82	2,428	1,498	666	47,124	.173	2.6	26.3
N. W. Central......	46.16	32.44	6,520	2,540	17.60	6.86	7,991	3,944	1,812	254,956	.188	5.7	34.7
Far W. and S. W...	13.68	7.80	6,420	2,580	16.10	6.41	1,442	858	374	37,007	.137	2.7	46.8
Pacific...............	8.16	7.79	(7.500)	3,760	23.15	11.60	577	552	143	11,033	.116	1.9	62.2
Total U. S.. ...	128.59	93.32	7,690	2,930	14.50	5.50	20,116	14,548	4,976	648,295	.213	6.2	36.1
1885.													
New England......	7.70	9.17	8,780	2,670	13.20	4.04	2,007	2,596	755	42,584	.31	6.6	28.3
Middle	55.75	28.88	11,600	4,070	16.40	5.65	7,502	6,034	1,451	321,843	.42	17.9	27.6
No. Central........	46.99	25.61	5,790	1,900	19.70	6.45	7,968	3,994	2,400	262,195	.20	6.4	30.7
So. Atlantic...	8.60	1.99	3,500	1,100	5.07	1.60	1,540	1,016	422	28,069	.13	2.4	23.4
Gulf and Miss......	12.12	.60	4,350	1,450	5.50	1.84	1,315	808	326	32,063	.14	3.3	30.6
So. West..........	21.84	7.02	4,670	1,690	12.00	4.35	2,475	1,190	599	63,005	.12	2.9	36.9
No. West	18.28	2.89	4,790	2,030	9.20	3.92	1,604	838	374	38,580	.12	3.0	34.9
Pacific.............	15.01	1.52	5,700	2,520	18.40	8.16	926	814	217	17,180	.13	2.4	35.8
Total U. S . .	186.25	77.67	6,220	2,170	12.86	4.48	25,937	17,290	6,544	805,519	.20	6.3	29.5

The groups of States are those of Poor's *Manual*, which see for the years 1882 and 1886 for details. The population used for the first part of the Table (1881) was that of the Census of 1880, which was about three per cent too small.

By a different estimate, the number of inhabitants, of acres in grain and cotton, of bushels of grain and bales of cotton produced, per mile of railway, have been as follows for the last seven years, in all cases taking the mileage and population at the close of the year and the crops, etc., of the previous summer :

	Population.	Acres.	Bushels of Grain.	Bales of Cotton.
1879	581	1,565	31,600	67.73
1880	545	1,466	28,932	70.53
1881	509	1,359	19,804	52.65
1882	473	1,236	23,405	60.18
1883	466	1,204	21,563	47.00
1884	458	1,216	23,690	45.44
1885	461	1,216	23,241	50.41

TABLE 22.

STATISTICS OF REVENUE PER HEAD OF POPULATION AND PER MILE FOR EACH STATE SEPARATELY—1881.

[These statistics are based upon the same figures as those given for groups of States only in the first part of Table 21. The division of the miles of road operated between the different States is not exact, so that the figures can be regarded as approximations only.]

	Per Mile Railway.		Per Cent. Sidings.	Per Cent. Operating Expenses.	Gross Revenue.	
	Square Miles	Population.			Per Mile Railway.	Per Head Populat'n.
Maine	[illegible]	[illegible]	10.0	60.0	$4.130	$6.54
New Hampshire	[illegible]	[illegible]	17.0	64.0	5.200	10.90
Vermont	[illegible]	[illegible]	15.4	80.5	4.690	12.40
Massachusetts	[illegible]	[illegible]	63.0	71.3	10.200	16.50
Rhode Island	[illegible]	1,810	40.5	61.4	9.200	5.90
Connecticut	[illegible]	[illegible]	35.0	64.0	9.650	16.00
New England	[illegible]	[illegible]	37.4	70.0	8.420	13.10
New York	[illegible]	848	[illegible]	61.0	13.000	15.90
New Jersey	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	28.10
Pennsylvania	[illegible]	[illegible]	[illegible]	[illegible]	15.800	23.70
Delaware	[illegible]	[illegible]	......	[illegible]	2.880	4.08
Maryland and D. C.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.30
W. Virginia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.60
Middle States	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.50

TABLE 22.—*Continued.*

	PER MILE RAILWAY.		Per Cent. Sidings.	Per Cent. Operating Expenses.	GROSS REVENUE.	
	Square Miles.	Popula-tion.			Per Mile Railway.	Per Head Populat'n.
Virginia	15.3	602	13.0	65.6	5.590	7.00
N. Carolina	31.4	228	6.4	66.5	2.590	2.70
S. Carolina	25.2	738	7.1	68.0	3.250	4.04
Georgia	22.1	586	7.7	60.7	3.740	6.14
Florida	70.7	344	5.0	62.8	3.210	1.61
Alabama	22.0	551	8.6	69.9	4.150	6.43
Mississippi	100.3	2,470	5.4	65.9	3.320	1.03
Louisiana	26.0	594	11.1	71.0	8.080	10.40
Tennessee	24.0	811	22.0	67.7	4.500	4.36
Kentucky	13.4	569	13.1	55.8	5.590	5.90
Southern States	25.7	681	10.9	65.0	4.550	5.20
Ohio	5.08	202	29.6	62.8	8.790	20.50
Michigan	13.9	400	29.6	68.2	5.850	12.40
Indiana	5.65	331	27.0	76.5	5.750	17.30
Illinois	5.20	288	27.0	54.7	7.560	29.05
Wisconsin	10.2	249	10.6	59.7	3.930	14.70
Minnesota	21.0	199	7.0	61.4	4.370	15.90
Missouri	14.3	478	11.4	54.0	7.000	13.60
Iowa	24.2	718	9.9	64.0	3.570	13.92
N. W. Central States	9.90	351	21.3	60.9	6.520	17.60
Nebraska	....	226	17.0	53.7	1.160	....
Wyoming	....	303	....	....	....	....
Dakota	....	254	....	....	....	....
Kansas	....	283	7.5	62.8	5.170	....
Colorado	....	95	5.9	61.1	6.530	46.90
Arkansas	....	1,200	5.9	58.5	3.960	....
Texas	....	309	3.9	68.0	4.480	....
Far W. and S. W.	61.9	310	7.1	60.2	6.420	16.10
New Mexico	....	230	....	....	....	....
Arizona	....	104	....	....	....	....
Utah	....	148	....	49.3	....	....
Nevada	....	140	....	53.8	....	....
California	....	301	13.7	49.5	8.620	....
Oregon	....	230	....	56.4	....	....
Pacific States	181.0	261	9.6	49.9	(7.500)	23.15
United States	29.0	481	25.1	61.9	7.690	14.50

TABLE 23.

MAIN RESULTS OF OPERATION OF THE RAILWAYS OF THE NEW ENGLAND STATES, 1873–1881.

YEAR.	Population. 1 = 1,000,000.	Miles Railway Operated.	Revenue. 1 = $1,000,000.				Dividends.	Revenue per head.			Rev. per Mile. 1 = 1,000
			Pass.	Fght.	Total	Net.		Pass.	Fght.	Total	
1873......	3.644	5,303	22.36	29.31	51.68	15.06	9.00	6.15	8.03	14.18	9.73
74......	3.696	5,617	22.11	27.95	50.06	16.71	8.51	6.00	7.55	13.55	8.91
1875......	3.748	5,732	21.78	26.55	48.33	15.32	8.79	5.80	7.10	12.90	8.41
1876......	3.801	5,783	20.52	25.24	45.76	15.38	7.61	5.44	6.67	12.11	7.90
77......	3.853	6,036	20.07	24.52	44.59	13.74	6.98	5.21	6.36	11.57	7.38
78......	3.905	5,760	17.97	23.29	41.26	13.69	7.57	4.60	6.00	10.60	7.18
79......	3.958	6,156	17.52	23.81	41.33	15.59	7.24	4.45	6.02	10.47	6.71
1880......	4.010	6,071	19.32	29.44	48.76	17.19	8.00	4.82	7.37	12.19	8.00
1881......	4.062	6,261	20.17	32.71	52.88	15.92	11.14	4.98	8.05	13.03	8.43

TABLE 24.

MAIN RESULTS OF OPERATION OF THE RAILWAYS OF THE MIDDLE STATES, WITH MARYLAND AND WEST VIRGINIA, 1873–1881.

YEAR.	Population. 1 = 1,000,000.	Miles Railway Operated.	Revenue. 1 = $1,000,000.				Dividends.	Revenue per head.			Rev. per Mile. 1 = 1,000
			Pass.	Fght.	Total	Net.		Pass.	Fght.	Total	
1873.....	10.915	12,441	42.36	151.7	194.1	69.3	36.5	3.88	13.90	17.78	15.6
74......	11.123	12,874	41.70	144.8	186.5	90.2	37.6	3.26	13.00	16.26	14.5
1875......	11.331	13,173	40.77	134.9	175.7	65.6	39.4	3.60	11.84	15.44	13.3
								3.58	12.91	16.49	14.5
1876......	11.540	13,647	47.48	130.1	177.6	69.4	33.7	4.10	11.30	15.40	13.3
77......	11.749	13,607	39.26	116.7	155.9	61.0	24.9	3.34	9.90	13.24	11.4
78......	11.958	14,600	35.95	119.5	155.5	61.6	21.1	3.00	10.00	13.00	10.6
79......	12.167	14,941	43.20	127.1	170.3	70.4	23.9	3.55	10.45	14.00	11.3
1880.. ...	12.376	14,882	44.97	154.0	199.0	83.9	28.5	3.63	12.40	16.03	13.3
1881......	12.585	16,213	49.92	178.5	228.4	84.9	33.3	3.97	14.20	18.17	14.1

TABLE 25.

MAIN RESULTS OF OPERATION OF THE RAILWAYS OF THE SOUTHERN STATES, (SOUTH OF POTOMAC AND OHIO), 1873–1881.

TABLE 26.

MAIN RESULTS OF OPERATION OF THE RAILWAYS OF THE WESTERN AND SOUTHWESTERN STATES (ALL NORTH OF OHIO AND WEST OF THE MISSISSIPPI AND EAST OF THE ROCKY MOUNTAINS), 1873–1881.

YEAR.	Population. 1 = 1,000,000.	Miles Railway Operated	Revenue. 1 = $1,000,000.				Dividends.	Revenue per head.			Rev. per Mile. 1 = 1,000
			Pass.	Fght.	Total	Net.		Pass.	Fght.	Total	
1873	16.025	32,973	51 62	160 1	211 7	72 5	19 06	3 23	10.00	13 23	6 42
74 ...	16.589	35,639	56 78	158 1	214 9	75 5	16.61	3 42	9 53	12 95	6.02
1875 .	17.154	36,058	54 99	151 2	206 2	75 6	19.23	3 21	8 80	12 01	5 73
1876 .	17.718	36,753	43 36	142 9	189 2	63 9	17.39	2.45	8.07	10.52	5 95
77.. .	18,282	39,136	44 44	148 8	193 2	66 1	14.56	2 43	8.13	10 56	4 95
78 ...	18.847	41,605	49 00	160 9	209 9	78 0	19 34	2 60	8 53	11 13	5.05
79 ...	19.411	44,104	54 45	177 9	232 4	99 0	23 56	2 80	9.16	11.96	5 27
1880	19.976	45,911	64 10	226 5	290.6	125 2	33.12	3 21	11.30	14.51	6 34
1881.. ..	20 540	53,224	71 40	273 0	344.4	134.8	40 85	3 48	13.30	16.78	6 49

TABLE 27.

MAIN RESULTS OF OPERATION OF THE RAILWAYS OF THE PACIFIC STATES, 1873–1881.

YEAR.	Population. 1 = 1,000,000.	Miles Railway Operated.	Revenue. 1 = $1,000,000.				Dividends.	Revenue per head.			Rev. per Mile. 1 = 1,000
			Pass.	Fght.	Total	Net.		Pass.	Fght.	Total	
1873	1.124	1,612	(5.9)	(10.3)	(16.2)	(9.3)	(2.6)	5.26	9.17	14.43	10.2
74	1.185	1,639	6.27	10.48	16.77	9.85	3.26	5.99	8.83	14.12	10.2
1875	1.246	1,790	6.70	15.74	22.44	12.23	5.43	5.39	12.60	17.99	12.5
1876	1.307	1,867	7.64	16.37	24.01	11.75	4.53	5.85	12.50	18.35	12.9
77	1.368	3,109	7.89	16.56	24.65	11.32	4.58	5.76	12.10	17.86	7.9
78	1.429	3,617	8.53	17.35	26.88	12.97	(6.0)	5.97	12.07	18.04	7.4
79	1.490	3,663	8.86	18.08	26.44	9.97	1.63	5.93	12.17	18.10	7.24
1880	1.551	3,813	8.82	19.92	28.74	10.79	3.99	5.68	12.77	18.45	7.53
1881	1.612	5,418	10.11	26.43	36.54	18.64	7.79	6.28	16.40	22.68	6.75

TABLE 28.

MAIN RESULTS OF OPERATION OF THE RAILWAYS OF THE ENTIRE UNITED STATES, 1871–1885.

86. Experience has shown that THE PROBABLE NUMBER OF TRAINS PER DAY is at once the most convenient and the most exact basis for arriving at estimates of probable future traffic, and especially expenses. It is the most convenient, because it can be more easily and more correctly anticipated than any other item of future business,—as tonnage, for example,—and also because we use the same unit for all our traffic, both freight and passenger; and it is the most exact, because it is by very much the most uniform, measure of operating expenses, the cost of a train-mile being very nearly the same whether the trains are run full or empty, or long or short, and not being materially different for freight or passenger service, although usually less, by one third to one fourth, for the latter, as we shall see hereafter.

Assuming, therefore, this basis for estimates, it may be always anticipated that there will be one passenger train per day each way, and that, unless the traffic be exceedingly limited, this train will be exclusively for passengers. Mixed trains, so called, are in but little and decreasing favor with railway managers, although it is not always possible to avoid them. When used at all, they are usually nothing more than freight trains under another name—accommodations for a few passengers being added chiefly as a convenience to special classes of travel, in the hope that such additional convenience may have, as it usually does, a favorable influence on the volume of travel. With freight traffic of course no such motives intervene to modify the number of trains, so that mixed trains are always freight trains carrying a few passengers, and never, in regular service, passenger trains carrying freight.

87. Therefore, under the most unfavorable circumstances there are pretty sure to be two regular trains per day, one passenger and one freight or "mixed" train, over lines of any length. Less than this is certainly never contemplated on lines built as private business enterprises, unless on very short branches built as feeders.

88. The point at which it becomes reasonable to anticipate running two regular passenger trains daily is more difficult to determine.

In the Northeastern third of the United States, as may be seen by examining any railway guide only a very small proportion of the minor branch lines run only one passenger train a day, and but a very few of the lines run as few as two passenger trains a day. In the North Central United States, including both slopes of Mississippi Valley, two passenger trains per day may be said to be the rule, exceeded only in the more populous regions and on the important trunk lines; but only a small proportion of the lines run as few as one train a day. In the Southern and extreme Western States the mileage may be said to be about equally divided between one train per day and two, only a few leading lines or sections of lines running more than two trains per day. In England and on the Continent the average number of passenger trains per day is much greater than in the United States, except in the extreme Northeast: but this distinction is constantly growing less with the rapid increase of population and wealth in the United States. Tables 29 to 78 give many statistics of the average number of trains per day on single roads, and in groups of States.

89. There are immense local fluctuations in every State and Territory, but as a rule, when the conditions are at all favorable for the development of passenger travel, a minimum of two trains per day may be looked for with some confidence. This is especially probable because, in order to encourage and develop traffic, it becomes expedient to put on two trains a day long before a single train becomes so crowded as to actually compel it. The greater facilities so offered are almost certain to add a considerable percentage to the aggregate travel and revenue; and as the actual additional cost of the extra train is, on the contrary, but a small percentage of the average cost per train-mile, such a train is almost always put on long before the mere statistics of tickets sold begin to indicate that it is a necessity. It is impossible, in fact, until the volume of travel becomes large and the number of passenger trains at least two or three per day, to make any attempt to regulate the number of trains so as to have them run full, without serious injury to net revenue.

90. Beyond three or four trains per day there is much less necessity, as a rule, to add trains to accommodate and develop travel until the seating capacity itself becomes too small; this being one of the many cases in which "the destruction of the poor is their poverty." Nevertheless the results of experience with even the heaviest traffic is that it does not pay to scrimp train facilities. Certain trains carry enormous loads and bring up the average materially, but a multitude of trains carrying much lighter loads are run with the heaviest traffic, at frequent intervals, bringing about the close correspondence in average train-load on roads of widely different character shown in Table 29.

TABLE 29.

AVERAGE FREIGHT AND PASSENGER TRAIN-LOAD, HAUL, TRAIN SERVICE, ETC., FOR THE UNITED STATES AND GROUPS OF STATES, 1885.

	FREIGHT TRAFFIC.					PASSENGER TRAFFIC.		
	Average Train-Load.	Average Haul. Miles.	No. Trains per day.	Miles per Engine. 1 = 1000	Ton-Miles per Car. 1 = 1000	Average Train-Load.	Average Haul.	No. Trains per Day.
A. New England	102	60	3.74	19.8	42.4	59	16	4.52
B. Middle	179	91⅛	7.42	21.3	53.9	44⅛	18⅛	4.64
C. No. Central	139	145	4.44	26.3	72.8	38⅛	37¾	2.33
D. So. Atlantic	93⅛	108	2.43	19.8	60.9	32	39⅛	1.52
E. Gulf and Miss. V.	125	103	2.31	21.0	61.3	43	48	1.64
F. So. Western	118	132	2.17	20.6	58.1	36	49	1.36
G. No. Western	148	159	2.13	17.9	69.6	47¼	60	1.21
H. Pacific	115	162	1.81	14.4	51.8	69⅛	31⅛	1.35
Total U. S., 1885	143	112	3.81	21.6	57.4	43¼	26	2.36
" " 1884	134	112	4.05	22.1	56.0	42⅛	26¼	2.51
" " 1883	126	110	4.48	22.8	56.6	46¾	27¼	2.41
" " 1882	129	109	5.32	21.3	53.8	45¼	26	2.37
U. S. Census, 1880	129	111	3.91	22.4	....	41⅛	21	2.16

Excepting the figures for 1880 from the U. S. Census, the above is computed from the statistics of Poor's *Manual*. In this, as in all other tables in this volume, the railroad year is taken at 365 days, owing to the regrettable fact that the distinction between Sunday and week days is fast disappearing. The "number of trains" always means *each way*.

TABLE 3[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1870	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$0.77
71	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
73	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
74	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1875	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.47
77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
78	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
79	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1880	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
81	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
82	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
83	[illegible]	[illegible]	[illegible]	1.74	[illegible]	[illegible]
84	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1885	[illegible]	[illegible]	[illegible]	1.41	[illegible]	0.42

TABLE 31.

STATISTICS OF PASSENGER TRAFFIC, LAKE SHORE & MICHIGAN SOUTHERN RAILWAY, 1870–1885.

Year.	Passenger Train-Miles, 1–000.	Average Paying Load, No.	Average Haul, Miles.	Per Passenger Train-Mile. Receipts.	Expenses.	Profit.
1870	[illegible]	69.2	77	$1.97	$1.22	$0.75
71	[illegible]	60.5	70	1.86	1.22	0.64
72	[illegible]	61.5	74	1.79	1.2[illegible]	0.59
73	[illegible]	60.8	63	1.72	1.22	0.50
74	[illegible]	68.7	56	2.02	1.32	0.71
1875	2,744	60.1	52	1.70	1.24	0.46
76	[illegible]	67.2	56	1.70	1.16	0.53
77	[illegible]	58.4	50	1.65	1.10	0.56
78	[illegible]	58.2	49	1.71	0.85	0.86
79	2,334	63.2	50	1.73	0.91	0.82
1880	2,540	69.1	53	1.78	0.92	0.86
81	[illegible]	72.9	56⅛	1.77	1.00	0.78
82	3,837	72.2	55	1.86	1.00	0.85
83	3,403	63.4	55	1.70	0.99	0.71
84	1,460	55.1	52⅛	1.51	0.87	0.64
1885	1,482	50.8	51	1.38	0.83	0.54

TABLE 32.

TRAFFIC STATISTICS, LAKE SHORE AND MICHIGAN SOUTHERN RAILWAY

Year.	Miles Road.	Per Mile Operated.			Dividends.	
		Earnings.	Expenses and Taxes.	Net Earnings.	Earned.	Paid.
1870............	1,013	13,336	8,261	5,075	9.60	8.00
71............	1,074	13.872	9,106	4,766	8.37	8.00
72............	1,136	16,682	11,177	5,505	8.55	8.00
73............	1,154	16,824	11,928	4,896	6.10	4.00
74............	1,178	14.592	9,491	5,101	6.04	3.25
1875............	1,178	12.284	8,963	3.321	2.20	2.00
76............	1,178	11,851	8,135	3,716	3.26	3.25
77............	1,178	11,484	7,622	3.862	3.57	2.00
78............	1,178	11,877	7.210	4.667	5.61	4.00
79	1,178	12,975	7.591	5.384	7.24	6.50
1880............	1,178	15,922	8,846	7,076	11.28	8.00
81............	1,178	15.261	9.577	5,684	8.02	8.00
82............	1.274	14.306	8,679	5,627	8.37	8.00
83	1,340	13,817	8.211	5,606	8.11	8.00
84............	1,340	11,075	6,815	4,260	4.02	5.00
1885............	1,340	10,545	6,929	3,616	1.98	....

The Lake Shore and Michigan Southern Railway being one of the few important lines which have been operated under substantially similar conditions and with substantially the same mileage and motive-power for fifteen years, its statistics have an especial interest, and Tables 30, 31, and 32 are added for that reason.

It is not expedient, nor indeed possible, therefore, to base estimates of the probable number of passenger trains on estimates or statistics of the probable number of passengers to be carried, further than to assume that the smaller the traffic the smaller will be the average number of passengers per train.

91. The same is true, in less degree, even of estimates of the probable number of freight trains. It is not correct to assume a certain tonnage to be moved, divide that by the load of a car to get the number of loaded cars, divide that again by the number of cars per train, and so get the number of trains. There is

always, in the first place, a certain wastage of capacity amounting to anywhere from ten to thirty per cent, according to circumstances, which, if the traffic is to be estimated on the basis of tonnage, must be allowed for. This wastage also, as with passenger business, is a much less serious matter on lines of large traffic, especially those with a heavy excess of tonnage in one direction; for in this case, although the average car-load in both directions is much reduced, yet in the direction of heaviest traffic the obtaining of full loads is facilitated. A very heavy disproportion of traffic, from three or four to one, exists on nearly all east and west lines in the United States; and most of them succeed in filling up their average car-load and train-load, in the direction of the heaviest traffic, to very nearly its nominal ca-

TABLE 33.

GROWTH OF AVERAGE FREIGHT-TRAIN LOAD OF VARIOUS ROADS, 1873 TO 1885.

YEAR..	NEW YORK TRUNK LINES.			MINOR TRUNK LINES.					
	N. Y. Cent.	N. Y., L. Erie & W.	Penna.	B. & Alb.	Del., Lack. & W.	Can. So.	Mich. Cent.	Pitts., Ft. W. & C.	P., C. & St. L.
1873	129	....	111	75	....	....	....	88	89
74	139	.. ....	122	81	79	....	....	89	103
75	166	134	128	82	83	....	135	96	98
76	180	138	132	87	83	....	147	97	116
77	166	145	137	88	78	....	158	96	129
78	186	146	154	92	93	155	167	116	140
79	191	185	170	94	77	190	195	120	156
80	219	211	184	97	....	208	201	125	166
81	218	218	184	102	90	275	186	132	155
82	219	228	189	104	86	....	172	132	165
83	200	211	189	103	99	184		131	160
84	196	213	205	106	99	198		139	161
85	204	227	209	109	107	202		138	182

pacity. Nevertheless, even on such lines, fluctuations and irregularities of traffic are always so great, that it is no infrequent spectacle to see trains running light in the direction of heaviest traffic; and the difficulty of fully filling up trains, of course, becomes much greater as the tonnage is less, or, as already stated, when it is nearly equal in each direction. There is also always one train per day, the way-freight, which averages little more than one half an ordinary train-load, owing to the irregular service.

TABLE 33.—*Continued.*

PENNSYLVANIA RAILROAD, BY HALF-DECADES.

(For the figures for each year, and for direction of heaviest traffic only, see Index.)

1853-5.	1856-60.	1861-4.	1865-70.	1871-4.	1876-80.	1881-5.
75.4	83.2	94.3	104.4	116.8	155.5	196.0

These figures not unfairly represent the general law of growth in train-load in the past 30 years under favorable conditions.

YEAR.	CHICAGO ROADS.					MINOR WESTERN ROADS.			
	Ill. Cent.	C., R. I. & P.	Ch. & Alt.	C., M. & St. P.	C. & N. W.	O. & M.	L. & N.	C., C., C. & I.	Wisc. Cent.
1873	83	....	....	76	107	....	....	79	....
74	94	....	119	74	101	....	....	81	....
75	90	81	124	87	99	....	....	86	53
76	97	80	142	86	108	....	....	89	60
77	97	99	139	87	110	....	....	90	55
78	112	85	138	83	122	115	....	99	72
79	115	95	161	80	122	121	120	112	96
80	110	107	177	55	132	133	....	122	....
81	103	104	184	72	132	129	121	191	112
82	120	109	189	81	132	107	....	205	....
83	100	106	188	86	121	126	....	218	....
84	120	105	190	93	126	103	....	205	....
85	116	105	184	98	132	152	137	212	100

Below the cross-lines in the second, third, and fifth columns there was a large increase of mileage operated, as also in some cases not marked. Most of the other cases in which the train-load has decreased are due to a falling off in total ton-mileage.

The enormous increase in average freight-train loads which has taken place in recent years, without any considerable changes of grades, and often without much change in the motive-power likewise, is shown in Table 33, as also in Table 30 and others.

92. Nevertheless, it still remains true that in the main, excepting the "way-freight," the freight traffic can be and is regulated in close accordance with the volume which offers from day to day. So many freight trains, usually from two to six, are put upon the time-table. If more are needed, "extras"—a train running behind another train and "on its time," but with a certain number of minutes' interval—are added, sometimes to the number of a dozen or twenty, and very frequently from two to six; the leading train, and each succeeding "extra" except the last, carrying a red "flag" as a signal that another train having its time-table "rights" is following.

On the other hand, if less trains are needed than appear on the schedule, such and such trains are abandoned for the day—often for days and weeks together, even when other trains are running extras. A near approach to conditions which actually obtain in practice will be given by assuming that the number of daily freight trains will always be one more than is nominally required by the tonnage, and often more, the office of the extra trains being simply to serve as equalizers.

93. The time-table or schedule, in fact, is, as regards freight traffic, nothing more than a row of hooks to hang the trains on as required. If one or a dozen of the hooks stand empty, no great harm is done. As trains come in or are made up, they are started off as either "regulars" or "extras" indifferently—whichever will give quickest despatch; some little effort being made indeed to send out at least one train on each schedule train's time, on account of the practical inconvenience and danger of frequent abandonment of trains; but the chief purpose in preparing freight schedules is not to give a separate time to each train, which are often behind time, but to afford an established method for despatching regular trains promptly at any hour desired. More or less uniformity naturally prevails in the business from day to day, but there is also much irregularity.

On the crowded Eastern division of the Erie, running often a hundred trains per day, there are but TWO regular scheduled trains, one for A.M. and one for P.M., and all others are run as sections of this train.

94. It should be mentioned also that, in attempting to draw conclusions as to probable traffic from statistics as to "miles run by freight trains" on neighboring roads, such statistics must be accepted with the greatest caution. An unfortunate custom exists of comparing locomotive expenses on the basis of the engine-mile instead of the car-mile, and as a consequence a habit has arisen among master mechanics and other officers of exaggerating the switching mileage (which is heavy enough at best) in every possible manner, by heavy allowances for switching at stations, and for running to and from the round-house. Instances might be given in which the excess of this nominal mileage over that actually run between termini amounted to nearly one fifth, independent of the usual and regular switching allowance of so many miles per hour to switching engines proper, which is separately given. This fact is important to remember not only in estimating the volume of traffic, but also in estimating locomotive expenses; for most roads make more or less allowance for mileage outside of the regular revenue distance, and it is always more or less deceptive, consequently, to use such data uncorrected for estimates of cost per revenue train-mile. Whenever there is a marked discrepancy in the cost per train-mile on similar roads this cause may with some confidence be regarded as the true explanation. Some reasonable approach to a correct estimate of the probable traffic can thus be made, by a little effort, from published statistics of various roads and towns, unless in a region which is entirely new to the railways, or for other exceptional causes. The following statistics will also be of assistance:

95. The average payment to railroads of each man, woman, and child in the United States now averages about $13.50, of which about $3.50 is for passenger transportation and $10 for freight. Table 34 and several others (see Index) give further statistics for various groups of States, but the fluctuations from such averages are of necessity great. Points which are centres of manufacturing and transportation interests will have a many times greater traffic than this to dispose of; while, on the other hand, there are few local stations which will fall very far below it, the great excess of the few points being compensated by the great multitude of small deficiencies.

TABLE 34.

RECEIPTS PER INHABITANT BY SECTIONS (DOLLARS).

	Passenger Payments Per Head.							Freight Payments Per Head.						
	N. E.	Mid.	W. & S. W.	Pacific.	Av. N. & W.	Southern.	Av. U. S.	N. E.	Mid.	W. & S. W.	Pacific.	Av. N. & W.	Southern.	Av. U. S.
% Population...	8.0 %.	24.7 %.	39.8 %.	3.1 %.	75.6 %.	24.4 %.	100 %.	8.0 %.	24.7 %.	39.8 %.	3.1 %.	75.6 %.	24.4 %.	100 %.
1871........	....	....	....	....	....	....	2.76	....	....	....	....	....	....	7.44
72........	....	....	....	....	....	....	3.24	....	....	....	....	....	....	8.40
							3.00	....	....	....	....	....	....	7.92
1873........	6.15	3.88	3.23	5.26	....	1.38	3.30	8.03	13.90	10.00	9.17	....	3.49	9.30
74........	6.00	3.26	3.42	5.99	....	1.26	3.30	7.55	13.00	9.53	8.83	....	3.41	8.85
75........	5.80	3.60	3.21	5.39	....	1.22	3.16	7.1	11.84	8.80	12.60	....	3.22	8.27
	5.98	3.58	3.29	5.31	3.77	1.29	3.25	7.56	12.91	9.44	10.20	10.42	3.37	8.81
1876........	5.44	4.10	2.45	5.85	....	1.03	3.01	6.67	11.30	8.07	12.50	....	3.37	8.00
77........	5.21	3.34	2.43	5.76	....	0.84	2.71	6.36	9.90	8.13	12.10	....	3.54	8.50
78........	4.60	3.00	2.60	5.97	....	0.99	2.61	6.00	10.00	8.53	12.07	....	2.66	7.62
79........	4.45	3.55	2.80	5.93	....	0.94	2.92	6.02	10.45	9.16	12.17	....	2.70	7.92
80........	4.82	3.63	3.21	5.68	....	0.86	2.93	7.37	12.40	11.30	12.77	...	3.10	7.32
	4.90	3.52	2.70	5.84	3.35	0.93	2.84	6.48	10.81	9.04	12.32	9.63	2.87	8.07
1881........	4.98	3.97	3.48	6.28	3.91	1.38	3.37	8.05	14.20	13.30	16.40	13.16	3.76	10.72

The course of earnings since 1881 is sufficiently indicated by the two following and other tables:

TABLE 34.—*Continued.*

FOREIGN COUNTRIES.

		Miles.	Pass.		Fr'ght
1876	Great Britain and Ireland....	16,658	5.19	(Total of all earnings, $9.20)..	4.01
1880-1..	France....................	15,227	....	(" " " 5.66)..	....
1880 ...	Austria....................	7,086	1.78	(" " " 5.28)..	3.50
1880	Italy....................	5,418	0.55	(" " " 1.33)..	0.68
1881.. ..	Mexico (one railway only)....	293	0.06	(" " " 0.53)..	0.47
1876-80..	So'n U. S. (E. of Miss. Riv.)..	11,892	0.93	(" " " 3.80)..	2.87
	N. and W. U. S.............	66,714	3.35	(" " " 12.98)..	9.63
	Total U. S...............	78,606	2.84	(" " " 10.91)..	8.07

From the above statistics we may conclude that the average revenue to railways from each inhabitant of the different sections—bearing in mind that much of the trunk-line freight traffic credited to the Middle States is in reality a part of New England and Western payments—is (average of 1880–85) about as follows:

	Pass.	Freight.	Total.	Ranging from
New England States	$5.00	$8.00	$13.00	$6.50 to $16.50
Middle States........................ ...	3.50	11.00	14.50	4.08 to 28.10
Western and Southwestern States.......	3.00	11.50	14.50	....
Pacific States..........	5.50	14.00	19.50	....
Average of all Northern and W'n States.	3.50	11.00	14.50	....
Southern States (E. of Miss. River).....	1.00	3.50	4.50	....
Average of the entire U. S.............	3.00	9.00	12.00	....

The fluctuations from year to year hardly exceed 10 to 15 per cent more or less of these averages. There is, however, a gradual yearly growth in the payments per inhabitant amounting to an average of perhaps one per cent per annum, due largely to causes considered in Chapter XXI.

The fluctuations in the average payments of different localities are no doubt extreme, as may be seen from the statistics in other tables. The State of Florida pays but $1.60 per annum to its railways. The larger Eastern cities, probably $30 per head at least. There are doubtless considerable sections of each of the States in the above groups where the payments may be as low as half or as high as double the average for the whole group of States. *The trunk-line export traffic* constitutes only an insignificant fraction of the total revenue of United States railways, large as it is absolutely.

CHAPTER V.

OPERATING EXPENSES.

96. We may gain a profitable insight into the general nature of the causes which modify operating expenses, and especially of the effect thereon of differences of alignment, by first considering them in a very general way, neglecting all detail.

We have previously (Chap. III.) compared the railway to a great manufacturing establishment—manufacturing transportation. Its operating expenses, to carry out the analogy, should be only another name for the total cost of producing the commodities which it sells; but as a matter of fact this is not the case. The interest or "rental" charge on its real estate, and on most of its machinery and plant—the heaviest single item by far in the real "operating" or manufacturing expenses—is never included in what are called the operating expenses, but constitutes the FIXED CHARGE for interest on bonds (see Figs. 1, 2, 3). Counting in the "fixed charges" as part of the "operating" or manufacturing expense, the latter never amount to much less than 80 per cent, and from that to considerably over 100 per cent, for long periods of time. The average for the whole United States is somewhat under 90 per cent, leaving but little more than 10 per cent profit on the goods sold to be distributed to the managing companies. Under favorable circumstances this profit is as much as 15 or 20 per cent; very rarely more. Tables 35 and 36 give a clearer idea of the law in this matter.

97. As these fixed charges increase in somewhat faster ratio than the cost of construction, and are the same per year whether the business be large or small or none at all, the great importance of (1) diminishing the expenditure for construction as much

TABLE 35.

STOCK AND BONDS PER MILE OF ROAD BY SECTIONS OF THE UNITED STATES.

1880.

Groups of States.	Miles.	Stock and Bonds Per Mile. 1 = $1,000. Stock.	Bonds.	Other D't.	Total.	Revenue per Mile. 1 = $1,000.
New England.........	5,910	31.6	21.5	2.75	55.85	8.00
Middle...............	14,942	47.5	49.3	2.87	99.67	13.30
Southern.............	12,978	15.8	19.2	1.37	36.37	3.56
Western..............	46,102	24.8	22.7	1.48	48.98	6.34
Pacific..............	4,461	33.2	35.8	2.58	71.58	7.53
United States.........	84,393	28.4	27.3	1.86	57.76	7.31
Canada...............	....	....	....	....	....	....

1885.

Groups of States.	Miles.	Stock.	Bonds.	Other D't.	Total.	Revenue per Mile.
New England.........	6,412	31.8	21.9	2.46	56.16	8.87
Middle...............	18,595	57.3	53.6	4.87	115.77	11.53
Southern.............	20,584	20.2	24.6	1.20	46.00	3.66
Western..............	74,854	25.2	25.6	1.49	52.29	5.25
Pacific..............	7,284	34.0	28.5	2.20	64.70	4.55
United States.........	127,729	30.9	29.5	2.03	61.43	6.22
" 1884.....	....	30.1	29.3	2.0	61.4	6.76
" 1883.....	....	30.8	28.7	1.9	61.4	7.54
" 1882.....	....	30.7	28.3	1.9	60.9	7.60

The nominal cost of road and equipment for the whole United States was for these years:

1882.	1883.	1884.	1885.
$52,790	$55,500	$55,300	$55,100

The Canadian railways average but $11,000 of bonds per mile, and $58,230 of stock and bonds together. Excluding the Grand Trunk, which, with 26 per cent of the mileage, has 45 per cent of the capital, there are only $28,000 per mile of both stock and bonds. More than one fourth of the total capital (145 millions out of 558, for 9,575 miles, in 1884) was contributed from governmental sources. Earnings are correspondingly small, being for 1884:

Canada Southern, } Grand Trunk, }	2,950 miles	$10,600 per mile. / 6,290 " "
36 remaining lines,	6,625 "	2,010 " "
	9,575 miles,	3,491 per mile.

TABLE 36.

DISTRIBUTION OF GROSS REVENUE, IN PER CENT OF TOTAL RECEIPTS.

1880.

GROUPS OF STATES.	PER CENT OF RECEIPTS DEVOTED TO—			
	Op'g Exp.	Net Rev.	Interest.	Dividends.
New England..........	68.1	31.9	11.25	16.83
Middle................	62.4	37.6	19.33	14.24
Southern...............	63.5	36.5	16.84	7.43
Western................	53.9	46.1	16.98	11.72
Pacific.................	50.2	49.8	23.05	14.50
Total U. S..........	58.3	41.7	17.58	12.55

1885.

New England..........	69.8	30.2	13.53	16.10
Middle................	64.7	35.3	27.56	13.92
Southern...............	67.3	32.7	27.14	3.40
Western................	65.0	35.0	22.24	9.06
Pacific.................	55.7	44.3	45.00	4.57
Total U. S..........	65.1	34.9	24.52	10.05

UNITED STATES FOR EACH YEAR FROM 1879 TO 1885.

1879..................	58.8	41.2	21.18	11.72
1880..................	58.3	41.7	17.58	12.55
1881..................	61.1	38.9	18.32	13.30
1882..................	63.6	36.4	20.02	13.23
1883..................	63.8	36.2	21.00	12.38
1884..................	65.2	34.8	22.90	12.09
1885..................	65.1	34.9	24.52	10.05

as true economy permits, and (2) increasing the traffic (sales) so that this burden may constitute a less percentage of the entire business, is evident. Omitting them, the OPERATING EXPENSES PROPER (corresponding to the expenses of simply running and maintaining a factory which has once been thoroughly equipped, and of selling the manufactured products) amount usually to

about two thirds, or 67 per cent, of the receipts, varying however enormously (from but little over 50 to more than 90 per cent) with different roads. Table 37 and others give an idea of the general tendency for a long period of years.

As the ratio of expenses to receipts may be made less either by the receipts being larger or the expenses being smaller, the fact that the ratio is low or high is no real test of economy in operation, nor of the value of the property. Wherever, from absence of competition, the rates are very high,—as formerly on the Pacific railways, Panama Railroad, and many lines in Europe,—this ratio will be small, even in the face of heavy expenses. Wherever all or nearly all railways have been very costly, as largely throughout Europe, it will also be small, since the fixed charges will constitute a larger proportion of the tax on earnings, and rates will naturally adjust themselves to pay (1) all operating expenses, (2) all rental or fixed charges, and (3) a fair profit to the managing company.

Wherever several lines are so situated that their business is largely competitive, and must be handled at the same gross price, but one or more of them has better grades, or a shorter line, or more traffic, or other special advantages, one line will permanently show a lower percentage of expense than the others, which will have no meaning as an indication of real excellence of management. This latter law is strikingly illustrated by the trunk-line percentages in Table 37, the cause for the differences in which is explained in a following note and in Chap. XXI.

98. The operating expenses proper are very irregularly affected by the amount of business or by the character of the alignment. A very large proportion of them are, like the rental or fixed charges, independent of both: such as the salary of the president and other officers; maintenance of works and plant against the deterioration which comes with time, irrespective of work done; salaries of local freight and passenger agents, a large proportion of whom must be employed anyway, whether considerable sales are made or not. This immense class of the expenses amounts, as we shall see, to nearly one half of the

TABLE 37.

PERCENTAGE OF OPERATING EXPENSES TO REVENUE.

DATE.	TRUNK LINES.				SECTIONS OF U. S.					
	N. Y. C.	Erie.	Penn.	B. & O.	N. E.	Mid.	W. & S. W.	So.	Pac.	Av. U. S.
1850–60	.....	.....	45.0	No statistics available.						
1861–65	[illegible]	51.0	62.5							
1866–70	[illegible]	[illegible]	[illegible]							
1871–75	[illegible]	[illegible]	[illegible]							
1876–80	[illegible]	[illegible]	[illegible]							
1871–[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	64.7	66.6	43.8	64.2
1876–80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61.2	65.8	56.5	60.9
1881	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55.5	61.1
1882	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	63.6	63.6
1883	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	66.5	63.0	[illegible]
1884	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60.2	[illegible]
1885	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	55.7	[illegible]
1881–85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59.6	63.8

[illegible]	[illegible]	54.6
[illegible]	[illegible]	54.8
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible] the number of years for which the average is [illegible] States are those of Poor's Manual for the years [illegible]

[illegible] marked tendency exists to increase or [illegible] which—as may be seen from [illegible] about equally.

[illegible] are often extreme, as may [illegible] maximum of efficiency [illegible] being incapable of essential [illegible] conditions. Thus the [illegible] the highest receipts [illegible] will [illegible] compare still more [illegible] traffic [illegible] always more [illegible] the Penn- [illegible] traffic which [illegible] more striking [illegible] Southern, Sea Islands, and [illegible]

operating expenses proper—the other half only varying more or less closely with the details of the line and grades, and very much less than half with slight changes in volume of traffic.

99. Therefore, it may be said in a general way that *ten* per cent added to revenue is as good as *fifteen* per cent taken off operating expenses; and this again means *thirty* per cent taken off that portion of the operating expenses which varies with line and grades. To gain or lose ten per cent in revenue by slight differences in the route selected is very easy. To reduce the whole operating expenses fifteen per cent by differences in alignment which do not increase the cost of construction, is not so easy. Let us illustrate, by examples free from detail, the very important moral conveyed in these facts. We will assume the case of a fairly prosperous line of the second grade, whose income and outgo we shall find may be distributed in something like the following manner:

	Per Cent.	Per Mile.
Gross revenue,	100.0	$7,000
Operating expenses, *unaffected* by either alignment or volume of traffic (50 p. c. of operating expenses),	33.3	$2,333
Ditto, *increasing directly with considerable changes* in alignment or volume of traffic, but not with trifling changes (40 p. c.),	26.7	1,867
Ditto, *increasing directly with the less important changes* in alignment or traffic (10 p. c.),	6.7	467
Total of nominal operating expenses,	66.7	$4,667
Add to the latter the rental or interest charge (6 p. c. on $30,000 per mile, assumed cash cost of road and plant),	25.7	1,800
Total of true operating expenses, or cash cost of producing the transportation sold,	92.4	$6,467
Surplus available for dividends being the business profit resulting from operation,	7.6	$533

Let us now see the effect of increasing or decreasing the gross revenue ten per cent, as it is frequently possible to do (one

might perhaps more fairly say, rarely difficult to do) by probable differences of alignment alone. We have, if it has been increased:

	Per Mile.	Per Cent Increase.
Gross revenue (increased 10 per cent), ...	$7,700	10.0
Operating expenses (10 p. c. only increased 10 p. c.), or $47 per mile increase, ...	4,713	1.0
Fixed charges (assumed unchanged), ...	1,800	0.0
Total charges against revenue, ...	6,513	0.7
Surplus available, ...	1,187	119.0

The surplus available for dividends is more than doubled.

On the other hand, if there has been ten per cent loss of traffic, we have—

	Per Mile.	Per Cent. Decrease.
Gross revenue, ...	$6,300	10.0
Operating expenses (10 p. c. of 10 p. c. only decreased 10 p. c), ...	4,620	1.0
Fixed charges, ...	1,800	0.0
Total charges against revenue, ...	6,420	—

The expenses are a little over the receipts, and the road is on the way to a receivership, if it has been opened, as it is very apt to be, in one of the years in which an ebb in the business tide is beginning, and there is no apparent growth (often a decrease) in traffic for several years.

100. Again: Let us suppose that, by an improvement of or injury to the line and grades, we increase or decrease the average train-load 30 per cent—often not difficult to effect. Our account, if we have improved the grades, will then stand as follows:

	Per Mile.	Per Cent.
Gross revenue, ...	$7,000	0.0
Operating expenses (30 p. c. of 50 p. c. saved, or $700),	3,967	15.0
Fixed charges (as above), ...	1,800	00.0
	5,767	
Surplus available for dividends, ...	1,233	131.0

Or, we have benefited the line greatly indeed, and yet but little more than if we had added 10 per cent to revenue. On the other hand, reversing this process, we find, as before, that the road is on the way to a receivership.

101. Let us suppose, by an unnecessarily extravagant scale of expenditure, for purposes which do not really add much in dollars and cents to economy of operation, we have increased the capital account or rental charge 33 per cent, in a way which does not decrease operating expenses more than 2 per cent, nor add anything to revenue—a not uncommon case, since the use of 6° instead of 10° maximum curves will alone suffice to do it, in some cases. We have then

	Per Mile.
Increased the rental charge 33 p. c., or	$600
Decreased operating expenses 2 p. c., or	93
Net increase, ...	$507

Or within $26 of wiping out the surplus over expenses and fixed charges. If we have, in addition, adopted a line which, instead of being better, is really more expensive to operate than another line which would have cost no more—or if, possibly, we have adopted a line which, in addition to being more expensive, involves a certain sacrifice of revenue, a receivership is practically assured. Both of these are very probable contingencies, but if we have escaped them, we have barely saved ourselves. The profit from the enterprise is destroyed.

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102. A great change has taken place within the past ten or fifteen years, and indeed is still in progress, in the operating expenses of railways, as a result of the introduction of certain modern improvements, and notably the steel rail. At so recent a period as the publication of the first edition of this treatise (1877) these improvements had hardly begun to tell at all upon the statistics which were available for its preparation; but they have already (1885) modified them profoundly, and where the process will end it is impossible to foresee with

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exactness—further than that the change will be very much more radical than even yet appears upon the surface.

103. Besides the steel rail, there has been a great increase in the power of locomotives. The old eight-wheel "American" locomotive, then almost universal for freight as for passenger service, is now almost completely out of use for heavy freight service. Mogul or Consolidation locomotives are rapidly superseding it, and will in the near future almost wholly supersede it. On all but roads of very light traffic the Consolidation locomotive appears to be the engine of the future; and a still heavier type, the "Mastodon" locomotive, has been introduced, with excellent prospects of wider use.

104. The capacity of ordinary freight cars has also been increased from ten or twelve tons to fifteen and twenty tons, with but a comparatively slight increase in the weight. In fact the 20-ton car has already become the standard both for coal and all other traffic, and many 25-ton and not a few 30-ton cars have been built. The movement in their favor has gone so far that a committee of the Master Car-Builders' Association has reported standard dimensions for such a car, but it is as yet regarded as exceptional, but many 25-ton cars are already in use, and it may confidently be expected that the average car-load will increase for many years. It has increased fully 50 per cent in the past ten years.

105. Still other—comparatively unimportant—changes which are gradually reducing the cost of operating are, first, the creosoting or otherwise preserving of cross-ties (a practice in small but increasing use); and, secondly, the substitution of first-class ballast for what has heretofore done duty for that purpose.

The almost incredibly rapid growth of traffic (see Tables 21 to 34, and others) has been perhaps the most potent factor of all, and these causes, and the gradual fall in the cost of producing every form of manufactured commodity consumed by railways, render it impossible to predict with any certainty either the future cost of a train-mile, or the ratio which the various expenses will bear to each other. The changes of the next ten years

Note to following table. The group of States marked * includes a very small high-rate mileage. Rates of 8, 9, 10, 13, 15, and 44 cents.

TABLE 38.

RECEIPTS, EXPENSES, AND PROFITS PER TON-MILE.

For the whole United States the earnings per ton per mile were:

1880	1881	1882	1883	1884	1885
1.29	—	1.236	1.236	1.124	1.057

The receipts per ton per mile in the various sections of the United States, according to the Census of 1880, were:

GROUP.	I. New Eng.	II. N. Y., D. C., Ind.	III. Va., Ky., Miss.	IV. Ill., Mo., Minn.	V.* La., Ark., Ind. T.	VI. Far W. and So.	U. S.
Receipts	1.83	1.02	2.15	1.36	12.57*	2.57	1.29
Average haul—miles	55.7	106.1	103.7	153.3	34.6	166.9	111.
Tons per train......	90.6	163.6	55.5	122.8	61.3	95.5	129

the British railways has been in the cost of maintenance of road. This has fallen from 15.70 cents per train-mile in 1874 to 12.76 in 1879 and 11.64 cents in 1884. *Per mile of road* expenses ranged, for the five years from 1874 to 1878 inclusive, from $1,865 to $2,020 for maintenance of road, and averaged $1,965. Then they fell off suddenly to $1,690, and have never been so low since, ranging thence to $1,800 in 1883 and $1,750 in 1884, and averaging $1,751 from 1879 to 1884.

The total expenses per mile of road have ranged from $9,665 in 1875 and $9,625 in 1883 to $8,775 in 1879, and the gross earnings averaged $17,690 for the five years from 1874 to 1878, reaching the maximum, $18,255, in 1885.

will probably be greater than those of the last ten, and all that we can be sure of is that the cost per ton-mile (not probably per train-mile) will continue to fall rapidly, although it hardly seems possible that it can fall quite so rapidly as in the last ten years. Table 38 and others will show the recent changes in the cost per ton-mile, and Table 39 the changes in the cost per train-mile.

106. Nevertheless, it fortunately happens that those items of expenditure with which we are more immediately concerned—those which are affected by the location of the line—may be anticipated with reasonable certainty from known facts and tendencies, although it is not expedient to rely too much on existing statistics of the immediate past of railways in respect to some items, as notably steel rails; since it would tend to the dangerous error of overestimating the probable expenses.

107. The operating expenses of railways divide, naturally, for the purpose which we have immediately in view, and in the main for all purposes, into the three great classes below :

1. MAINTENANCE AND RENEWAL OF WAY AND WORKS, including all permanent structures and buildings, except engine and car-shops.

This has until recently averaged very uniformly 25 per cent of the total expenses on all American railways. It is now decreasing both relatively and absolutely, but far less rapidly than might be expected, because of both temporary and permanent causes below mentioned.

2. TRAIN EXPENSES, including all expenses of every nature and kind connected with the running, handling, maintenance and renewal of motive-power and rolling-stock, but not includ-

ing any station or terminal expenses, except switching. These expenses have heretofore averaged very close to 42 per cent of the total operating expenses, and cost from 30 to 50 cents per train-mile. They have decreased considerably per train-mile for the same class of engines, but the introduction of heavier engines will have a tendency to keep them more nearly constant. Relatively to the other operating expenses they are growing continually more important.

3. STATION, TERMINAL, AND GENERAL EXPENSES AND TAXES. With these we are very little concerned. Most of them vary more or less (for the most part, less) with the tonnage or volume of business; but all of them are independent of, or inappreciably affected by, any of the details of lines and grades, and therefore, for our present purpose, may be included together and neglected, except as to their aggregate. Taxes at first sight appear to be affected by the alignment, in so far as they might increase with the length of the road; but taxes are based upon value and not on cost, and hence, although nominally based upon distance, are in reality much more truly based upon low grades, large traffic, and good rates. They are, moreover, too small and variable an item to justify their consideration as one of the expenses affected by any of the details of alignment. Station expenses also, and all the other expenses mentioned, are the same for the same business, whatever changes in the alignment may be made, except as such change brings additional way business; but even then the change will rarely be sufficient to appreciably modify the station expenses. For its indirect value in such cases and others, and as a matter of general information, Tables 75 to 80 give what the cost of the various items of station and general expenses amount to on various roads and in various sections.

MAINTENANCE OF WAY.

109. The steel rail has revolutionized maintenance of way. Previous to its advent the great trunk lines were engaged in an unceasing struggle, which was rapidly becoming hopeless, to maintain their lines in a decently safe and passable condition. Much of this difficulty was due to

the most culpable carelessness as to the quality of rails purchased; but the difficulty existed, and was only partially remediable at best. The cost of rail wear alone per train-mile was from 7 to 9 cents, and their life on important lines was measured by months rather than years.

Under these circumstances the track was constantly disturbed, the ties cut full of spike-holes, the joints imperfect and irregularly spaced, owing to the constant cutting of rails, the line and surface difficult to maintain correctly, and anything like a permanent rock ballast well-nigh out of the question, although it was occasionally used. As a further and very natural consequence all maintenance expenses for the above items varied to a very remarkable degree, in almost exact ratio with the tonnage and rail wear—as indeed they still do, but to a less noticeable extent. Some evidence of the former conditions is still preserved in Table 40, but further space need not be devoted to the discussion of conditions which no longer exist to any extent.

110. The superiority of the steel rail lies not so much in its greater strength and toughness (although it is stronger by 20 to 30 per cent) as in its greater homogeneousness and absolute freedom from grain. In other words, when of good quality it is tough enough to last until it is worn out, whereas the iron rail splits into pieces long before it has lost any serious amount by wear. The wearing properties proper of iron and steel rails—their resistance to abrasion—are not materially different.

111. The average life of GOOD steel rails properly manufactured and inspected so as to eliminate all imperfections arising from a lack of ordinary care and skill, and weighing 60 to 80 lbs. per yard, according to the weight of engine, has now been determined with a considerable approach to certainty to be about 150,000,000 to 200,000,000 tons, or (what is probably a more correct way of putting it) from 300,000 to 500,000 trains. From 10 to 15 lbs. or three eighths to five eighths of an inch in height of the head of such a rail is available for wear, and abrasion takes place at the rate of about 1 lb. per 10,000,000 tons, or one sixteenth inch per 14,000,000 to 15,000,000 tons. This durability may be regarded as nearly a minimum for strictly first-class rails, as many recorded observations indicate a much higher durability.

112. Unfortunately, it may be said to be the rule rather than the exception, that American railways now buy their steel rails, as they formerly bought their iron rails, without any effective inspection as to quality; the so-called inspections, when there is any even in form, being confined to the exterior qualities of the rail. Unfortunately, also, a few years since the result of an investigation on the Pennsylvania Railroad into the wearing

TABLE 40.

SHOWING THE FORMER PERCENTAGE (1865-75) OF THE VARIOUS ITEMS OF THE COST OF MAINTENANCE OF WAY, FOR A SERIES OF YEARS, ON DIFFERENT RAILWAYS AND FROM STATE REPORTS.

(From the former edition of this Treatise.)

The values in the last two lines may be regarded either as cents per train-mile or as percentages.

qualities of steel rails, which showed, or seemed to show, that very hard rails did not wear so well as softer and tougher rails, was taken to indicate that softness in itself was a desirable quality in a rail; and the painstaking character of the investigation and high reputation of the road having given these conclusions wide dissemination, manufacturers for many years took them as a guide, and between 1880 and 1885 produced rails which have deformed readily under the impacts of service, especially at the joints, and have also worn away very rapidly, so that their life has often been only a year or two under very moderate trunk-line traffic. In instances it has been only a few months.

113. The particular cause for this deterioration of quality, whether it is chemical or mechanical, or both, is as yet obscure. It is probable that as there has been no adequate inspection to enforce sound practice the chemical composition has suffered by the use of cheaper ores, cheaper men to supervise manufacture, and less care in all the processes. But a chief cause is probably mechanical—that the "bloom," or first rough casting of the steel from the converter, out of which the finished rails are fashioned, is, in the first place, heated unduly hot for passing through the rolls, and, in the second place, is passed through them a less number of times, or too rapidly, or both. In order to roll a rail very rapidly and with few passes it must necessarily be very hot, both to begin with and when it finally leaves the rolls. Its molecular structure might be expected to be disadvantageously affected by this lack of surface compression, independently of the fact that, being left to cool slowly after it leaves the rolls, it is thoroughly annealed by the same process as makes the finest tool steel soft enough to readily suffer deformation from dies. The rapid motion of the rolls, moreover, may not give the molecules sufficient time to flow upon each other properly, and a spongy, unhomogeneous metal is the result.

114. Whether or not this is the true explanation, it cannot be questioned that there is some equally simple and easily remedied explanation, because certain makers do produce rails of excellent quality which are sold at the same price as the inferior ones. The remedy, therefore, lies simply in more thorough tests, especially for ability to resist deformation; and it would be erroneous to conclude from this admitted but, it may reasonably be hoped, temporary evil that the estimate of cost of rail service should be permanently increased. The reasonable cost per train-mile of rail wear may, on the basis of the facts above given as to the life of rails, be estimated at from 0.3 to 0.5 cents, as follows:

Cost of one mile of steel rails, 95 long tons, at $30, . . .	$2,850
Less scrap value of unworn steel, say nearly half, ...	1,350
Leaving as net cost of wearable portion, per mile, ...	$1,500

Divided by total life of 300,000 to 500,000 trains, this gives 0.3 to 0.5 cents per train-mile; but, in view of the present difficulty of getting good rails, and tendency to increase the weight of trains, we may assume the even figure of 1.0 cents per train-mile as a maximum which there is no need of ever exceeding.

No allowance for interest or discount to represent the present value of the scrap is made in this estimate, nor should there be, although at first sight an argument to the contrary seems plausible. The whole original cost of the steel is a permanent part of the cost of the property on which interest must be paid, like the cost of the ties and structures. The renewals for each year simply represent, in the long run, the rail wear for that year, and no question of interest is involved in the cost of simply using the steel to run trains over.

115. The locomotive alone causes by far the greater portion of this wear; how much is not positively known. Freycinet, a French engineer, writer, and politician of much prominence, recently Minister of Public Works, estimates that the locomotive does three fourths of the damage and the train itself only one fourth. Launhardt, a German writer on the subject, after noting the fact that the locomotive and tender together constitute only one fifth of the total weight of train on the Prussian State railways (it would be considerably less in this country), considers that half the wear is due to the locomotive and tender and half to the train. This is all probably a very moderate estimate. Experience on the gravity railways of Eastern Pennsylvania, worked solely by inclined planes and carrying a heavy coal traffic with the ordinary vehicles, and with all other usual conditions except that no locomotives run over the rails, shows that the [illegible] is very slight indeed under heavy tonnage [illegible] but exact figures of the wear cannot be [illegible] investigated this question somewhat by placing [illegible] between the rails and wheels and determining [illegible] He points out that the pressure of [illegible] resistance of the [illegible] area is very much less with ordi[illegible] substantially the above conclu[illegible] the total wear of the rails [illegible]

116. We may assume, therefore, the cost of maintaining fairly good steel rail at 0.5 to 1.0 cent per train-mile; the cost of additional engine-mileage, the car-tonnage remaining constant, being only half as great. These values, although in round figures, probably approximate very closely to the facts, and the very best quality of rail might reduce them one half; but the poorer qualities which have been so generally sold of late years greatly increase it, when so poor that the rail speedily mashes out of shape, and from this cause and renewals of the still remaining iron rails combined, 2 cents is nearer the present average (see Tables 75–80). Much of the rapid wear of rails results from the imperfections of the fish-plate type of joint which is now universal. Its defects of principle are such that it seems quite certain to be supplanted within a decade by something better—probably by something closely resembling in principle the Fisher "bridge" joint, if not identical with it.

TRACK LABOR.

117. This item includes all the considerable elements of cost in maintenance of way proper outside of rails, ties, and frogs and switches. It has been unmistakably falling in the last ten years, the decrease on many roads having been as much as fifty per cent. About one fourth to one third of this decrease is accounted for by the decrease in the rate of wages to what bids fair to be a permanent average of about $1.25. The remainder is almost wholly due to the advent of the steel rail. Except that the joints are still so weak and imperfect a detail, it would unquestionably fall very much more.

This decrease is destined to continue, but less rapidly, for some time in the future; and in making estimates of operating expenses for the next few years—if not for a long period ahead—the apparent indications of the statistics of other roads must be accepted with much caution. All the roads now laid with steel—with hardly an exception—are, instead of reducing track expenses to the lowest limit possible, maintaining for the time being something like the old rate of expenditure and perfecting the condition of their road by adding better ballast, dressing up the road-bed and right of way, improving their yards and switches, etc., etc. This wise procedure is in reality an addition to the capital account, but for obvious reasons of expediency it is still called and charged to maintenance of way.

118. It is also very evident that the larger the business of a road, i.e., the more prosperous it is, the more likely will it be to continue this process extensively. For example, the Pennsylvania Railroad, although laid with steel and ballasted with stone throughout, still includes a very heavy charge per mile of road (although not per train-mile) in its annual

accounts for "maintenance of way," the reason being simply that it is engaged in giving the last degree of finish to its road-bed, track, and right of way; and the same is true in a less degree of many other railways.

119. It is even possible that this practice will be continued indefinitely as a matter of permanent policy; and when it comes to dressing up the edges of rock ballast with a string, sodding and planting slopes, etc., etc., there is hardly any end to the labor which may be kept busily employed in "maintenance of way," nor can it be doubted that such expenditure would be returned in part, perhaps many-fold, by its value to the line; for its value lies not alone in the direct economy of such fine condition, but in its value as an advertisement, by making travel over the line more attractive, and likewise in its effect to instil habits of caution, neatness, and watchfulness into the entire force of employés. Nevertheless, such facts should not lead us to confound advertising and landscape gardening with "maintenance of way," nor blind us to the fact concealed from sight in the current statistics—and likely to be for some years yet—that the cost of maintaining steel-rail track is no longer greatly affected by the tonnage. It will for some time appear to be the case—as it came very near to being actually the case during the iron-rail period—that the total cost of maintaining track varies very nearly with the tonnage, and that it has not been so very largely diminished by the steel rail as was expected. Perhaps there is more that is permanent in this appearance than is expected, as certainly there is unless the current carelessness in buying bad rails at good prices is reformed: but the following estimates (par. 124) seem reasonable and sufficient.

120. CROSS-TIES alone cost from $120 to $225 per mile of main track, about 330 per year (one eighth of the total number) being required per mile of main track, at an average cost of, say, 50 cents per tie (it is often only 30 or 40 cents in favored localities), with about two thirds as many, or 220 per year, per mile of side track. Side-track ties will hardly average in cost, however, more than half as much per mile per year as main-track ties, being largely "culls," or of otherwise inferior quality.

In England and Europe generally the number used per mile is less—ordinarily 1760 per mile, or three feet apart, the dimensions being in England somewhat greater, usually 9 feet by 10 × 5 inches instead of 8 to 8½ feet by 6 × 8 inches, and the wood inferior fir instead of oak; and yet the average life of English sleepers is longer by about 50 per cent than in America, the difference being due in part to better ballast and road-bed, in part—perhaps mainly—to greater care to have the ties well seasoned before putting them in the track (in respect to which American roads are very careless), and in part to the use of cast-iron

chairs on English tracks to carry the rail and protect the sleepers from "cutting." The differences of practice in England and America result, for the most part, from differences of conditions, and not from mistakes of judgment on either side. Where wood of any kind is dear, hard wood out of the question, and labor and rails cheap, the English and Continental plan of widely spaced ties, with the rail carried in chairs, is at least defensible, although it may be questioned if there is any real economy in spacing ties so widely. Where good hard-wood ties are cheap it would be folly to space ties farther than two feet apart, or to use a rail requiring chairs. One effect of the English plan is that for equal stability and strength, very much heavier rails must be used than with the ties nearer together, which is the chief explanation of the fact that they are heavier.

121. The expense of cross-ties will probably be considerably reduced within the next ten years by the more general introduction of burnettizing or other equivalent processes, and it will then be almost wholly true, as it is now in part, that the life of ties is independent of the tonnage. The only way in which tonnage seriously affects the life of a tie, under a steel rail, is by helping on that process of local rotting which is popularly and erroneously known as "cutting" into ties. The difference in this respect between main-track ties (especially if of soft wood) and side-track ties, is very considerable; but, given three or four trains a day over the track, the effect of even twenty or thirty more trains a day is much less important, and the "cutting" does not take place noticeably faster. This results from the fact that the only real assistance which the train gives to the "cutting" is to wear away the rotted surface, so as to leave a fresh surface exposed to decay. It is physically impossible for the rail to cut into a sound tie under existing loads, except as assisted by the greater rapidity of rotting under the rail than alongside of it. That this is true is conclusively proved by the fact that creosoted or similarly preserved ties do not cut to any important extent, even when the wood is soft.

The importance of this distinction as to the cause of "cutting" is obvious; since it follows from it that the wear will not be very greatly increased by an increase in number of trains, beyond four or five per day whereas otherwise the wear of ties would be directly as the train-mileage.

122. Putting ties into the track costs about one third as much as the tie itself including all labor incident thereto, or about 15 cents per tie, or $50 to $75 per year. Including with this the maintenance of ballast and ditches and ordinary track-walking, but not including policing the right of way and road-bed, special watchmen, removing snow and ice, care of structures, or extraordinary repairs—the TOTAL COST OF TRACK LABOR, as thus defined, properly and necessarily chargeable to the main-

tenance of steel-rail track, once reasonably well ballasted and in good general condition, is not far from $300 per mile of single-track main line per year, or say five men for every six miles. This amount is only to a very limited extent affected by the volume of traffic if the standard of maintenance is not increased. It does not now appear probable that it can ever be materially reduced to advantage, since it is necessary to have that number of men available for emergencies for prudential reasons; and work can and will be easily found for that number, after the track has been brought in the course of years to a condition of far greater excellence than the present average, by continuing the present rate of expenditure, and not a few lines of the first rank will, by aiming at absolute perfection, permanently incur a still larger expense.

123. About $50 per mile of the above total will ordinarily go for track-walking, which is about all the expense for track watchmen that will usually be incurred on roads running only three or four trains per day each way. For a traffic beyond that, the usual expense per annum is about $5 per mile for each daily train round trip (or say three fourths of a cent per train-mile), up to a total of about $150 to $200 per mile, beyond which this account very rarely runs. Snow and ice is another source of irregular expense for "maintenance of way." It amounts to about $50 per mile of main line, single track, per year, and about $100 per mile of double-track road in ordinarily unfavorable regions—running much higher, of course, on short sections. Long shallow cuttings are the greatest sources of annoyances and expense in respect to snow and ice—a consideration often forgotten in fixing gradients.

124. The total cost of maintenance of way for single-track railways of moderate traffic may be safely estimated as follows, for those items only, which are practically independent of volume of traffic:

Cross-ties, ...	$150	to	$225	Per mile of main track, not including mileage of sidings. Common track labor $1.25 per day.
Do. for sides, ...	10	to	40	
Labor on track, ...	150	to	200	
Track-walking, ...	50	to	100	
Snow and ice, ...	0	to	50	
Ballast, ...	50	to	100	
Fences and miscellaneous, . .	25	to	50	
	$435	to	$765	
To which must be added for cattle-guards, open culverts, and crossings, about	25	to	50	
Total, ...	$460	to	$815	
Steel rails, say	20	to	100	

To this estimate must be added certain allowances for maintenance of structures, for the maintenance of large yards and terminal facilities, and for extraordinary damages and repairs, and also for the wear of steel, and other expenses, according to traffic. The amount of necessary expenditure which can with any propriety be assumed to vary directly with the tonnage will be—

Steel rails,	1 ct. per train-mile, or	$20 per 1,000,000 gross tons				
(including all expenses for relaying, spike, etc., connected therewith).						
Track labor, etc.,	1¼ cts. p. t. m.,	25	"	"	"	"
Track watchmen,	¾ " "	15	"	"	"	"
Total, . .	3 " "	$60	"	"	"	"

This amount will vary almost exactly with the number of trains, independent of their weight and length. As will be seen from Table 41, the present rate of expenditure for rail renewals, in all parts of the United States, is much higher than the above, or about $200 per mile, but this can hardly continue to be permanently the case.

125. Yet it must be admitted that there are some strange anomalies in the records of maintenance of way expenses which seem to indicate that such expenditures will continue to bear a nearly constant ratio to the train expenses proper, as they have in the past. For example, if Table 41 be examined, it will be seen that in every item of maintenance of way—even those which seem most nearly independent of the number of trains, like ties, bridges and buildings, repairs of road-bed and track—it is the cost *per mile of road* which varies, and that the cost per train-mile or the percentage of the total remains far more nearly constant. In fact, the cost of rails, which one might expect to be almost precisely so much *per train-mile*, comes much the nearest of all to being uniform *per mile of road*. Beginning with the section of heaviest traffic,—the Middle States group, which includes Ohio, Indiana, and Michigan,—the cost of rail renewals, in cents per train-mile, is

3.50, 4.08, 5.03, 6.08, 6.72, 3.66, averaging 4.43;

while that of road and track labor is

9.2, 11.0, 11.0, 8.7, 16.5, 8.3, averaging 10.2.

Individual roads may be compared almost at random with similar indications. The following two roads, not selected in any way except as

representing extremes of traffic, may serve as illustrations, the years given being fairly representative:

	Penn. R. R. 1883.	Char., Col. & Aug. 1882.	Av. U. S. 1880.
Trains per day each way (main line).....	64.5	3.4	6.1
Repairs road bed and track (cts. per train-mile)	9.81 cts.	12.36 cts.	10.2 cts.
Total cost of train-mile.................	86.0 "	87.5 "	91.0 "

Table 41.

Maintenance of Way Details.

Deduced from U. S. Census of 1880. See also preceding table.

Groups of States.	Trains each Way Per Day	Total Cost Per Train-Mile.	Cost Repairs Road-bed and Track. P. C. Expenses.	Cents Per Train-Mile.	Per Mile of Road.
[illegible]	[illegible]	[illegible]	[illegible]	11.0 cts.	$574
[illegible]	[illegible]	[illegible]	[illegible]	9.2 "	621
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] "	273
[illegible]	[illegible]	[illegible]	[illegible]	11.0 "	361
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] "	450
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] "	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	10.2 cts.	$450

[illegible] group averages are abstracts and large [illegible]

[illegible]	[illegible]	[illegible]	South.	N. W.	S. W.	Far West.	Total U. S.
[illegible]							
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.23
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$450
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]							
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	$307
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 42.

TRUNK-LINE MAINTENANCE EXPENSES IN CENTS PER TRAIN-MILE BY DECADES FOR 34 YEARS.

	Miles Run, Thousands.	Expenses Per Train-Mile. Maintenance of— Way.	Engines.	Cars.	Total Rolling Stock.	Total Expenses Per Train-Mile.	Percentages. Track.	Engines.	Cars.
N.Y.C.& H.R.		cts.	cts.	cts.	cts.	cts.			
1860	4,493	19.8	9.0	8.9	17.9	95.2	20.8	9.5	9.4
1870	11,430	39.8	9.8	15.4	25.2	122.2	32.6	8.1	12.6
1880	16,654	18.9	5.8	14.4	20.2	107.5	17.6	5.4	13.4
1884	16,453	24.8	5.3	10.3	15.6	108.6	22.8	4.8	9.5
Erie.									
1860	3,475	24.1	9.0	11.7	20.7	94.6	25.5	9.5	12.4
1870	9,326	39.6	14.1	12.0	26.1	129.5	30.5	10.9	9.2
1880	11,452	20.7	5.1	8.0	13.1	108.5	19.0	4.7	7.4
1884	11,305	18.2	4.4	8.9	13.3	106.8	17.0	4.1	8.3
Penna.*									
1860	3,633	21.4	7.7	8.2	15.9	99.3	21.5	7.8	8.3
1870	10,185	30.1	9.1	11.7	20.8	110.6	27.2	8 2	10.6
1880	17,241	14.5	7.2	10.5	17.7	81.8	17.7	8.8	12.9
1884	21,491	15.8	7.0	11.4	18.4	81.8	19.3	8.6	13.9
Balt. & Ohio.†									
1860	3,831	15.9	6.8	8.7	15.5	51.8	30.7	13.1	16.7
1870	7,941	26.3	6.9	5.5	12.4	68.8	38.3	10.1	8.0
1880	12,768	18.3	9.4	20.6	30.0	82.0	22.3	11.5	25.1
Phil. & Read.									
1860	1,853	11.2	8.6	8.9	17.5	78.6	16 5	10.9	11.3
1870	5,100	22.6	8.6	13.5	22.1	108.2	19.3	7.4	11.9
1880	7,799	26.3	7.8	12.1	19.9	117.5	22.4	6.7	10.3
1883	12,347	19.1	7.9	14.1	22.0	117.2	16.3	6.8	12.0

* Pennsylvania Division only. † Main stem and branches.

In Table 42 is given a record of expenses for maintenance of way on five trunk lines for the past 34 years. In this table, it will be noted, an enormous expansion of train-mileage has occurred, ranging from four- to seven-fold, while yet the cost of maintaining track has, on the whole, decreased less rapidly than other maintenance expenses. There has been, on each of these lines, a considerable expansion of track-mileage as well as train-mileage, but this increase has been of branches only, not of main line. Therefore, while due allowance for the effect of this greater

trackage would reduce, it will not seriously modify, the striking contrast in number of train-miles per year shown in the table, in spite of which maintenance of way has decreased, by comparison with other items, so little.

In the following table (43) the experience of the Pennsylvania Railroad only is carried back ten years further—to the very beginning of its operation, and every year's experience is included, the years being averaged together by half-decades to eliminate accidental variations and shorten the table. In this table, but not in the preceding, fuel, stores, and engine-wages are included with repairs of engines and cars in the single item "motive-power and cars:"

TABLE 43.

OPERATING STATISTICS OF THE PENNSYLVANIA RAILROAD (MAIN LINE AND BRANCHES) AVERAGED BY HALF DECADES FROM THE BEGINNING OF ITS OPERATION.

YEARS AVERAGED.	Average Miles Run. 1 = 1000.	Train Load E. only. Tons.	PER CENT OF TOTAL EXPENDITURE.		Per Cent of Maintenance of Way to Motive-power and Cars.
			Motive-power and Cars.	Maintenance of Way.	
1851–55...	1,416	101.6	42.3	13.4	31.7
1856–60...	2,934	110.6	42.9	23.7	55.4
1861–65...	5,530	146.24	48.1	22.8	47.5
1866–70...	8,766	158.88	41.4	27.2	65.6
1871–75...	14,368	187.76	38.2	23.4	61.3
1876–80...	16,182	251.32	39.4	18.4	44.3
1881–84...	20,808	298.45	41.7	20.0	48.0

The remarkable showing in respect to the growth of average train-load from 100 to in 1851–5 to 300 tons in 1881–4 is worthy of special note in this table. For average load both directions see Table 33.

The drop in the last two half-decades is the effect of the introduct of steel rails; but both in the iron-rail and steel-rail eras it will be s that the tendency of cost of maintenance of way *per train-mile* is to crease faster than the train expenses proper. The following table i brings this tendency out still more clearly:

TABLE 44.

COMPARATIVE COST OF MAINTENANCE OF WAY TO REPAIRS OF ENGINES AND CARS ON EACH OF THE FIVE LINES IN TABLE 42, COST OF REPAIRS OF ENGINES AND CARS BEING $1.00.

	N. Y. Cent.	Erie.	Penna.	B. & O.	P. & R.	Average.
1860......	1.11	1.16	1.33	1.025	0.64	1.053
1870......	1.58	1.51	1.45	2.12	1.02	1.536
1880......	0.945	1.58	0.82	0.615	1.32	1.056
1884......	1.59	1.37	0.86	...	0.87	1.172
Average.	1.306	1.405	1.115	1.915	0.962	1.199

The contrast in the proportionate cost of maintenance on the various roads is in part genuine, but in part no doubt results from considerable difference in what items are included in "maintenance of way" or of cars or engines. Less pains were taken in this respect than to have the comparison of one year with another correct for each road separately.

The last column of this table is the most instructive. With the exception of 1870, which was an abnormal year, it will be seen that the tendency of maintenance of way to *increase* in relative importance, in spite of an immense growth of traffic, seems marked and clear.

TABLE 45.

GROWTH OF ENGLISH TRAIN-MILEAGE AND COAL CONSUMPTION OF ENGINES PER MILE.

		Great Eastern.	Great Western.	London, B. & So. Coast.	Midland.
Train-miles (1 = 1000)....	1873	8,932	19,717	5,300	19.811
	1883	13,679	31,128	7,986	33 087
Increase per cent..........		52.0	58.0	50.8	67.1
Engine-miles............	1873	10,819	22,778	6,208	......
	1883	17,077	36,465	9,630	......
Increase per cent..........		57.8	60.3	55.2	......
Coal burned, lbs., per train-mile........	1873	41.65	41.73	43.33	57.18
	1883	45.96	37.69	37.07	49.00
Increase per cent..........		10.35	− 9.8	− 16.9	− 14.3
Coal burned, lbs., per engine-mile.............	1873	34.39	36.12	36.99	......
	1883	36.81	32.17	30.74	......
Increase per cent..........		7.05	− 10.8	− 20.3	......

The mileage represented above is 5,221 miles, or only a trifle less than one third of

that in Great Britain, and is fairly representative of the whole. The change in engine- and train-load is given only for the Great Eastern, as follows:

First-Class Goods-Engine, Great Eastern Railway.	1873	1883	Per cent increase.
Diameter of driving-wheels	5 ft. 3 in.	4 ft. 10 in.	8.6*
Cylinders	16½ × 24	17½ × 24	12.4
Total working weight, lbs	70,700	84,000	21.6
Working pressure	140 lbs.	140 lbs.	....
Coal Train:			
Consumption per mile	43.75 lbs.	46.68 lbs.	6.78
Speed, miles per hour	17.4	20	15.0
Average load.	398 tons.	438¾ tons.	10.2
Consumption per mile with average load, 400 tons.	43.97 lbs.	42.58 lbs.	D. 3.17

* Increase per cent in *power*, due to decrease of drivers. The *total* increase in power of the engine, due both to decrease of drivers and increase of cylinders, then becomes $108.61 \times 1.124 = 122.1$, or 22.1 per cent increase; almost exactly equivalent to the increase of weight.

The high average speed of English trains and the small power of a "first-class goods-engine" compared with usual American practice on lines of heavy traffic, are noticeable. The tendency of switching-mileage to increase comparatively is shown in this table to prevail quite as strongly in England as here.

The above figures are deduced from *The Engineer* of Jan. 23, 1885, which paper, however, makes some very erroneous deductions as to what they really show, pointed out in the *Railroad Gazette* of Sept. 11, 1885, by the writer.

Train Expenses.

Fuel.

126. The cost of fuel per gross ton on American railways ranges from a minimum of \$1.20 to \$1.50 on roads obtaining coal at mines on their own road, to a maximum of \$4.00 to \$5.00 at the least favored points east of the Missouri River, and in some cases to \$6.00 or more at points west of there.

The consumption of fuel is as an average about 45 to 50 lbs. per mile run for heavy passenger trains, running down sometimes as low as 25 or 30 lbs. per mile for light passenger trains. A passenger engine running light, without any train, burns nearly as much as this, or from 20 to 30 lbs. per mile. A heavily loaded freight engine of the "American" eight-wheel type will burn almost 75 lbs. per mile, a heavy "Mogul" about 90 lbs. per mile, and a "Consolidation" engine from 100 to 120 lbs. The weights and power of these and other engines will be found in Chapter

XI.; and from data given there, in connection with the above, it appears that the average consumption of fuel increases considerably less rapidly than the power of the engine, as might be expected.

TABLE 46.

MOTIVE-POWER EXPENSES PER TRAIN-MILE ON VARIOUS ENGLISH RAILWAYS.

MOTIVE-POWER EXPENSES IN DETAIL.	Great Western Railway, 1869–76.	Great Southern and Western, 1875.	Midland Great Western, 1875.
	cts.	cts.	cts.
Engine repairs—labor	3.76	2.82	3.42
" " —materials	2.46	3.80	2.78
Total engine repairs	6.22	6.64	6.18
Wages, engine crew	4.66	4.32	3.84
Fuel	4.34	6.61	6.50
Water	0.42	0.50	0.32
Oil and stores	0.48	0.66	0.82
Repairs shops, etc	0.12	....	....
Gas	0.10	0.32	....
Office and general	0.40	0.66	0.20
Total motive-power	16.74	19.76	17.90

The above is from a paper in the *Transactions* of the Institution of Civil Engineers, the reference to which the writer has lost.

127. Several newly invented types of compound locomotive engine, having separate high-pressure and low-pressure cylinders, are being extensively introduced in Europe with, it is said, very satisfactory results. If we may judge from what has already taken place in marine engines, it is probable that they will eventually come into general use, and they promise a considerable reduction of fuel consumption, but there are several practical disadvantages with the type which have not yet been fully overcome—notably a difficulty in starting. The burden of evidence seems to be that the coal consumption is reduced at the rate of about 20 to 25 per cent.

The consumption of fuel on English railways in general, however, is lower than prevails in the United States, although very much less so than commonly supposed. It was reported by the late Howard Fry, in a paper before the Master Mechanics' Association, at from 26 to 35 lbs. per mile run, for passenger service, and from 35 to 45 lbs. per mile run, for freight service ; but the following statistics, which have been compiled by the writer from later and more

definite statistics (Tables 45, 47,* 48, 49), show that the actual difference between English and American practice is less extreme.

It is unnecessary to enter in detail into the causes of the difference in English and American fuel consumption. The fact exists, and in part is easily explainable, by a difference in the average train-load; in part also, doubtless, to better road-bed and alignments, use of copper fire-boxes, and, more especially, greater skill and care in firing. The longer average trips of American engines, other things being equal, should reduce the average fuel consumption. The most important single cause is probably that fuel economy is subordinated in America to hauling heavier loads, as it ought to be, whereas in England heavy freight trains, or what would pass for such in America, are the exception.

TABLE 48.

PASSENGER-TRAIN COAL CONSUMPTION, PENNSYLVANIA RAILROAD.

YEAR.	Cars Per Train.	COAL PER MILE.	
		Per Car.	Total.
1874........	5.5	9.0	49.5
1875........	5.3	8.5	45.1
1876........	5.6	8.3	46.5
1877........	5.10	8.72	44.5
1878	5.13	8.43	43.2
1879........	5.29	8.40	44.4
1880........	5.27	8.76	46.2
1881........	5.01	10.78	54.0
1882........	5.14	9.61	49.4
1883........	4.95	10.84	53.7
1884........	5.02	10.67	53.6

The last column is not given in the reports, but is obtained by multiplying together the two preceding columns.

The increase of 18⅛ per cent in the coal burned per car, notable in this table, is undoubtedly the price paid for the very much greater average weight of passenger coaches, owing to the increasing proportion of parlor- and sleeping-car mileage, and the much greater average speed.

The Pennsylvania has been selected merely because its statistics are most conveniently accessible. It is in no respect pre-eminent either in increase of train-load or in low fuel consumption. The movement toward increase of train-load began on the Lake Shore & Michigan Southern, for example, several years before it began on the Pennsylvania. The Philadelphia & Reading runs about 58 lbs. per passenger train-mile.

* Table 47 was misplaced in making up this Part, hence was omitted from the volume.

TABLE 49.

AVERAGE FREIGHT-TRAIN COAL CONSUMPTION, PENNSYLVANIA RAILROAD.

YEAR.	No. Cars.	Train-load Tons Fr't Per Car.	Approx. Total W't of Train; Tons.	COAL BURNED PER MILE.		
				Per Ton Freight.	Per Car-Mile.	Per Train-Mile.
1874..	21.1	(6.5)	327	(.646)	4.2	88.5
1875..	21.5	(6.7)	....	(.627)	4.2	90.2
1876..	22.2	(6.9)	....	(.609)	4.2	93.1
1877..	22.92	(7.1)	....	(.585)	4.15	95.0
1878..	25.06	(7.3)	....	(.497)	3.63	91.0
1879..	25.60	7.55	436	.490	3.70	116.7
1880..	25.77	8.18	....	.477	3.90	112.0
1881..	24.40	8.68	....	.492	4.27	109.3
1882..	24.55	9.01	....	.494	4.45	104.3
1883..	23.97	10.28	....	.454	4.67	100.5
1884..	25.66	10.58	566	.430	4.55	99.2

The tons freight per car was obtained by dividing the coal consumption *per car* given by that *per ton*; the approximate total weight by assuming the average car to have weighed 18,000 lbs. (9.0 tons) in 1874, 19,000 lbs. (9.5 tons) in 1879, and 23,000 lbs. (11.5 tons) in 1884; the coal burned per train by multiplying the number of cars by the coal per car. The remaining figures are direct from the report.

The figures in parentheses above are estimated, not being given in nor deducible from the reports; but they are not far from the truth, a gradual increase of average car-load having, as is well known, been going on even in the years 1874-9, which has gone on much more rapidly since. One of the chief reasons why the average car-load has been so small, on all the American east and west trunk lines, has been the enormous disproportion (more than 3 to 1) in east-bound to west-bound traffic. The increasing coal shipments westward, to a considerable extent in cars coming east with grain, has in recent years helped much to decrease this disproportion on some roads; so that the increasing average car-load is not due solely to increased capacity of cars, although that is the chief cause.

The proportion of switching is very heavy on English railways, the ratio of engine-miles to train-miles being almost uniformly as high as 125 to 100, and in some cases, as high as 177 to 100.

On German railways the average consumption is about 50 lbs. per revenue mile, costing about six cents.

128. The cost of fuel per mile run can be calculated from the above data for any particular line. In absolute cost, it is by far the most variable element in the running expenses of railways, but its percentage to the other expenses is considerably less variable, owing to the fact that

the same causes which make fuel more expensive, also increase the other expenses to a considerable extent. The total average cost per mile for all trains, according to railway reports at the present time, varies from 5 cents as a minimum (on the Pennsylvania Railroad), to about 10 cents in Massachusetts and 12 cents on the Pacific railways. There are a few roads in the Rocky Mountain region on which the reported cost runs still higher than this—up to as much as 20 cents; and, on the other hand, there are a few specially favored roads on which the cost runs still lower—down to 4 or even 3 cents: but these latter phenomena are mostly due to exaggerating the actual train-mileage with fictitious allowances.

TABLE 50.

EFFECT OF LENGTH OF TRAIN ON COAL CONSUMPTION.

[Comparative Coal Consumption with Light and Heavy Passenger Trains—Michigan Central Railroad.]

LIGHT TRAINS.

No. of Round Trips.	Av. No. Cars Handled.	Coal Consumption, Per Mile.			Av. Temp.	Per Cent Correction for Temp.	Corrected Lbs. Coal Per Mile.
		Min.	Max.	Av.			
3	5	58.	67.	62.3	21.4°	− 4.3	59.62
3	5½	55.5	65.5	61.	19.7°	− 5.15	57.86
2	6	62.1	60.7	61.4	31.2°	+ 0.6	61.77
1	6½	....	....	48.	40.8°	+ 5.4	50.60
9	5.56	58.5	64.4	60.0	25.2°	− 2.4	58.56

HEAVY TRAINS.

No. of Round Trips.	Av. No. Cars Handled.	Min.	Max.	Av.	Av. Temp.	Per Cent Correction for Temp.	Corrected Lbs. Coal Per Mile.
2	7½	74.6	84.0	79.3	22.9°	− 3.55	77.07
1	8	....	....	78.6	33.1°	+ 1.55	79.82
7	8½	71.8	87.0	79.4	29.5°	− 0.25	79.20
2	9	81.6	87.1	85.4	36.3°	+ 3.15	88.10
3	9½	73.6	79.3	77.3	44.2°	+ 7.10	82.80
1	11½	....	....	75.0	27.0°	− 1.50	73.88
16	8.78	75.4	84.4	79.3	32.4°	+ 1.20	80.25

NOTE.—The averages of maximum and minimum are mere arithmetical averages of the figures given. In the last column the total coal consumption was divided by the total mileage to get the average.

All these trains made frequent stops; 30 in 115 miles, or about one every four miles. Speed not given; probably over 30 miles per hour maximum between stations.

The correction for temperature is by a rule deduced by the writer from records covering many millions of train-miles, that *the effect of differences of temperature alone, length of train and all other conditions being equal, is to increase or diminish coal consumption at the rate of* ONE *per cent for each* TWO *degrees Fahrenheit* (and a small fraction more) *difference of external temperature:* a rule easily remembered and one which appears to apply fairly well to both passenger and freight service, and to be practically invariable whenever the effect of all other causes for variation can be eliminated.

Since the effect of increasing the average length of train from 5.56 to 8.78 cars, or 3.22 cars, is shown above to increase coal consumption from 58.56 to 80.25 lbs. per mile run, or 21.69 lbs., or at the rate of $\frac{21.69 \text{ lbs.}}{3.22 \text{ cars}} = 6.736$ lbs. per mile per car, we have,

	Lbs. coal per mile.
For the long train, burning,	80.25
Consumption due to cars, 8.78 × 6.736 =	59.14
Leaving as due to the engine alone, without cars,	21.11
For the short train, burning,	58.56
Coal consumption due to cars, 5.56 × 6.736,	37.45
Leaving as due to engine alone, without cars, as above,	21.11

This result agrees closely with what direct experiment has shown to be the consumption of heavy passenger engines running light. Mr. Reuben Wells some years ago made a test of a light passenger engine, 14 × 22 cylinders, running 108 miles with six stops at 22 miles per hour, and losing about one sixth of its time only in stops, with a consumption of only 18⅛ lbs. per mile, and this test was in warm weather. Allowing for the differences of weather, size, and number of stops, the correspondence is close, and other tests, which need not be referred to in detail, have shown from 20 to 30 lbs. Mr. William Stroudley, Mechanical Superintendent of the London, Brighton & South Coast Railway, alleges in a paper before the Institution of Civil Engineers (1885), that a heavy passenger engine was run light between London and Dover with a consumption of *only 7 lbs. per mile.* As the distance is only a little over 50 miles, however, and the quantity stated would amount to only a few inches over the bottom of the fire-box of 20 square feet, or barely as much as the same record shows was habitually used to get up steam, there is probably some error in this estimate.

The best existing direct evidence on the effect of length of train on coal consumption is given in Table 50. There is considerable difficulty in obtaining records of this kind, in which a series of trains of widely varying lengths are run with all other conditions approximately identical. The correctness of the result reached in Table 50 may be tested by grouping the various single records differently—a test which should never be omitted in computations of this kind, since it will often be found that, when grouped in one way, the records will appear to lead to one conclusion, while if grouped in another way they will indicate something quite different.

Tested in this way, the correctness of the preceding conclusions is confirmed. If, instead of averaging the single tests together in only *two* classes, of "light"

and "heavy" trains, we divide the 25 tests as tabulated above into four equal groups of six tests each, as nearly as may be, and see how well the rule determined beneath the table (lbs. coal per mile = 21.1 + 6.74 × No. of cars) checks with the actual coal consumption, we find a close correspondence, as follows:

No. of Round Trips Averaged.	Cars per Train.		Pounds Coal Per Mile.		
	Range.	Averages.	Actual.*	Computed.	Difference.
6	5 to 6	5.25	58.74	56.5	− 2.24
6	6 to 8	6.92	68.02	67.7	− 0.32
7	8 to 9	8.50	79.40	78.4	− 1.00
6	8½ to 11½	9.67	83.08	86.3	+ 3.22

* Actual consumption after correcting for difference of temperature.

The correspondence of the results under this entirely different grouping is surprisingly close, indicating that the whole series of tests do clearly conform to one general law, but also indicating that the addition to the fuel consumption is not precisely uniform per car, but decreases as the train is longer, as is but natural.

Having determined a law for experiments on a small scale, we may check it by records on a large scale, which latter do not otherwise afford the means of determining the law. The Pennsylvania Railroad, alone among American railways, publishes a table showing the coal consumption per car-mile and pe train-mile, and the number of cars per train for every month in the year. A an average of the four years 1881–84, the average passenger train and passenger car coal consumption on each of its three grand divisions was:

	Cars Per Train.	Pounds of Coal—	
		Per Car-Mile.	Per Train-Mile.
Pennsylvania RR. Div.	5.03	10.47	52.7
U. RR. N. J. Div.	4.70	12.60	59.2
Phila. & Erie Div.	4.20	12.10	50.8

Computing what ought to be the coal consumption per mile according to the rule of Table 50, and comparing it with what is, we have the following:

	Computed Coal Consumption. Pounds per Train-Mile.			Actual. Pounds per Train-Mile.	Error in Formula. + or −.	
	Due to Engine.	Due to Cars.	Total.		Pounds.	Per Cent.
Penna. RR. Div.	21.1	33.9	55.0	52.7	+ 2.3	+ 4.4
U. RR. N. J. Div.	21.1	31.7	52.8	59.2	− 6.4	− 10.8
Phila. & Erie Div.	21.1	28.3	49.4	50.8	− 1.4	− 2.8

The correspondence here is close, if we remember that the Pennsylvania Division, while making fewer stops than the Michigan Central train, whose record was used in table, has a large proportion of heavy sleeping-cars, while the New Jersey Division not only has a large proportion of parlor- and sleeping-cars on through trains, but makes an enormous number of stops on way trains, both into New Jersey and into Philadelphia.

129. The conclusion is, therefore, not unfair, that something like 6¼ to 6¾ lbs. of coal per mile is added to the consumption for each passenger car of 20 tons or more moved at way-train speed, and for each sleeping-car of 30 tons or more moved in through trains making few stops, and that the locomotive alone is to be charged with rather more coal than that due to three cars.

This leads to the conclusion that dead weight to the amount of 30 tons added to a train of, say, five cars, will certainly not increase coal consumption as much as to add another car, both because it does not increase air resistance, and because the added load decreases somewhat the rolling resistance *per ton*. If we assume it to add 5 lbs. per mile to the coal consumption, we are certainly not underestimating it proportionally. Adding 6 tons per car, therefore, to the average weight of a train of five passenger cars means no more than an increase from 55 to 60 lbs. per train-mile. If we assume this 5 lbs. of coal to be worth one cent (at the rate of $4 per ton of 2000 lbs. for coal), if an extra passenger at 3 cents per mile be attracted to the train every third trip he will pay for the loss of fuel due to adding 6 tons to the weight of every passenger car—which goes a little way toward explaining the tendency to increase weight for the sake of luxury, which seems so reckless. This appears to neglect the effect of the extra weight on grade resistance, and so in a sense it does, as well as many other effects, but not so much as it appears to, since the effect of gradients is included in the records which we have used.

The use of wood for fuel is rapidly passing out of date in all parts of the United States. About 1½ cords of good hard wood (a cord being 4 × 4 × 8 feet, or 128 cubic feet, and weighing from 3200 to 3600 lbs. when well seasoned) is usually taken as equal to one long ton of coal. Inferior woods will average from two down to even three cords of wood equal to one ton of good coal, but some of the poorer Western coals will evaporate only half or two thirds as much as good bituminous or anthracite.

REPAIRS OF ENGINES.

130. The fall in the cost of this item, of late years, has been very rapid, but it is probably now at about its minimum, unless and until some new process of manufacturing steel and iron shall materially reduce the cost

TABLE 51.

STATISTICS OF LOCOMOTIVE SERVICE ON THE PENNSYLVANIA RAILROAD, 1851 TO 1884.

YEAR.	No. of Locomotives	Per Cent in Shop.	Per Cent of Standard Patterns.	MILEAGE. 1 = 1,000,000.			Lbs. Coal Per Mile.	COST PER MILE RUN.			MILES RUN PER ENGINE.		LBS. COAL, CAR-MILE.	
				Pass.	Freight	Total.		Repairs.	Fuel.	Total.	Pass.	Freight	Pass.	Freight
1851	26	....	....	...	....	0.48	....	2.92	9.1	...	....	....	....	....
52	43	....	....	...	....	0.69	....	4.92	9.1	....	....	....	....	....
53	79	19.0	....	0.44	0.55	1.00	....	7.05	9.6	....	15.2	10.1	....	....
54	115	16.5	....	0.57	0.92	1.49	....	12.6	8.8	...	15.1	10.5	....	....
55	118	13.6	....	0.68	1.18	1.86	....	7.25	7.25	....	20.0	13.6	...	....
1851-5	104.0	16.4	....	0 563	0.883	1.416	....	7.06	8.77	....	17.4	11.4	....	....
1856	133	24 8	....	0.65	1.38	2.02	....	9 35	8.2	....	16.6	14 7	....	....
57	216	18.0	....	0.80	1.74	2.54	....	8.65	8.60	....	15.0	11.3	....	....
58	209	20.1	....	0.98	2.21	3.19	....	8.25	7.70	....	20.4	13.9	....	....
59	205	16.6	....	1.03	2.10	3.29	....	7.34	7.59	....	20.6	15.9	....	....
60	208	16.3	....	1.06	2.42	3.63	....	7.69	7.17	....	22.9	18.3	....	....
1856-60	194.2	19.16	....	0.904	1.970	2.934	....	8.26	7.852	....	19.1	14.8	....	....
1861	229	28.0	....	1.12	3.15	4.41	....	7.81	6.41	15.18	23.8	19.3	....	....
62	255	27.0	....	1.16	3.74	5.09	....	7.76	5.98	14.76	23.2	19.7	....	....
63	290	22.0	...	1.26	4.07	5.54	55.0	9.17	7.07	18.16	22.9	20.2	....	....
64	321	24.0	...	1.37	4.38	6.01	60.0	14.41	9.19	26.47	20.8	19.1	....	....
65	352	22.7	....	1.62	4.72	6.60	65.0	11.62	9.19	24.35	21.9	20.2	....	....
1861-5	289.4	24.74	....	1.306	4.012	5.530	60.0	10.15	7.568	19.784	22.5	19.7	...	....

1866	362	22.4	....	1.78	5.30	7.35	66.5	12.21	8.89	23.48	25.4	23.0	....	....
67	415	20.2	....	1.92	5.82	8.03	67.0	13.75	8.19	23.70	22.5	21.1	....	....
68	434	21.1	....	2.05	6.34	8.69	64.8	12.08	7.35	20.99	23.6	20.3	....	....
69	477	15.7	....	2.30	6.90	9.57	62.9	11.00	7.29	19.49	24.8	21.1	....	....
70	482	14.2	....	2.47	7.36	10.19	63.6	9.13	6.35	16.28	26.9	22.1	....	....
1866–70	434.0	18.72	....	2.104	6.344	8.766	64.96	11.62	7.614	20.788	24.64	21.52	...	....
1871	514	17.0	....	2.60	8.88	11.90	68.9	6.81	6.01	13.66	25.5	22.8	....	....
72	554	12.6	....	2.91	10.84	13.92	72.0	8.16	6.33	15.30	28.2	22.3	....	....
73	662	15.5	...	3.06	12.44	16.11	74.5	4.90	7.19	12.94	23.7	24.6	....	....
74	654	16.8	60.3	2.93	11.26	14.64	72.2	5.30	6.37	12.43	28.7	22.5	9.0	4.2
75	655	16.0	65	3.19	11.72	15.27	71.9	5.86	5.11	11.76	27.0	23.0	8.5	4.2
1871–5	607.8	15.58	....	2.938	11.028	14.368	71.90	6.27	6.202	13.218	26.62	23.04	8.75	4.2
1876	659	16.4	68.2	4.01	12.32	16.80	74.1	5.87	5.06	11.71	32.4	25.6	8.3	4.2
77	674	24.2	59.	3.55	10.91	14.89	73.8	5.43	4.42	10.56	28.5	22.0	8.72	4.15
78	648	18.7	62.7	3.62	11.22	15.24	71.5	4.66	4.28	9.50	30.7	24.7	8.43	3.63
79	643	21.8	64.7	3.76	12.57	16.74	75.1	5.00	4.30	9.79	32.7	27.8	8.40	3.70
80	627	12.5	84.4	4.27	12.51	17.24	77.9	7.29	5.14	13.00	33.5	27.0	8.76	3.90
1876–80	650.2	18.72	....	3.842	11.906	16.182	74.48	5.65	4.64	10.912	31.56	25.42	8.52	3.916
1881	640	12.2	(Nearly all.)	4.68	14.41	19.63	80.6	5.97	5.11	11.74	33.6	28.3	9.61	4.27
82	693	10.7		5.10	15.24	21.00	82.8	6.50	5.39	12.73	32.8	26.0	10.78	4.45
83	780	16.7		5.46	15.86	22.11	83.9	7.13	4.99	12.93	34.7	25.7	10.84	4.67
84	797	19.2		5.78	15.02	21.49	85.7	6.97	5.09	12.77	33.6	25.2	10.67	4.55

NOTES.—A small mileage was made during construction, 220,000 miles in 1849 being the earliest report, which is omitted. The Altoona shops were opened in 1852. There were then 2 eight-driver engines, weighing 43,000 and 51,000 lbs., all on drivers, and 7 six-driver engines weighing 57,000 lbs., with 42,000 on drivers. The remaining 34 engines, which were in service through the year, weighed for the most part 45,000 to 47,000 lbs., with 25,400 to 27,450 lbs. on drivers.

Running of engines first in, first out, first introduced over whole line in 1878.

The number of locomotives leased to other lines is deducted from the number given, whenever there were any such.

of the raw material, especially in shapes. For this purpose solid steel castings in lieu of forgings seem to be already on the verge of coming into general use.

The table (51) on pp. 140 and 141 shows the cost of engine repairs per engine-mile on the Pennsylvania Railroad for a long series of years, and sufficiently illustrates the general tendency of the cost of this item; the table showing however, it must be remembered, nothing more than the cost of labor and materials directly applied to repairs and renewals proper, without including any allowances or charges for repairs, and renewals of tools, shops, machinery, and other items, for which see Table 57 and others. The figures given are in all cases for what is now known as the Pennsylvania Railroad Division, excluding the later acquisitions of the Philadelphia & Erie Railroad, and United Railroads of New Jersey.

131. From the above table it appears that the cost per mile on the Pennsylvania Railroad, at the present time, is from 5 to 6 cents for engine repairs proper, and this may be considered the minimum under the most favorable circumstances, on roads having a heavy traffic and convenient to the great iron and coal centres. Many roads—perhaps most roads—show a lower average than this; but such a result, when it continues for more than two or three years, is very apt to be one of the before-mentioned miracles of bookkeeping, based upon running an unusually large mileage in the general office.

132. The Massachusetts roads average about 5½ cents—a surprisingly low average for that region of the country, but doubtless very nearly correct. It may be explained largely by the greater proportion of passenger trains (more than one half the whole, as against about one fourth in the remainder of the country), and also by the fact that a very excessive proportion of the freight traffic, as compared with the rest of the country, is mere way business with light loads. A densely settled region will of necessity reduce the average train-load heavily in this way.

133. Under unfavorable conditions, the estimate of engine repairs must be considerably increased from these figures, but by how much, as a maximum, is extremely difficult to determine. The Union Pacific Railroad reports repairs of engines at about 7 to 8 cents per train-mile, which is among the highest reported costs at the present time; and yet, except for the one disadvantage of locality, it is under exceptionally favorable conditions for a low cost in this item, its engines not being heavy and its grades very light, its divisions very long, and its traffic—quite light for a trunk line—almost entirely long haul, and moved at a slow speed. From 5 to 8 cents may be considered as about the present average, for

all classes of engines, on roads with sufficient traffic to have proper facilities for economy in shop work. Wages do not vary widely in any part of the United States, and no causes exist for very wide fluctuations in this item.

TABLE 52.

COST OF LOCOMOTIVE REPAIRS IN DETAIL.

Performance and Cost of Three Passenger Engines for Five Years, New York Central & Hudson River Railroad (Hudson River Div.).

Average mileage per engine for the five years included,	416,162
" " " " year,	83,232
" " " " month,	6,936
" " " " day in service,	278
" per cent of time idle for repairs or otherwise,	17.3%
" " for all engines of Pennsylvania Railroad from the beginning of its history (see Table 51),	17.9%

***The above table represents the very lowest cost at which locomotives can be operated* in actual service :**

First, Because the engines were entirely new at the beginning of the record, and although the record covers something over half the average mileage-life of a locomotive (which may be taken as 600,000 to 800,000 miles), yet the latter half of its mileage-life (including cost of renewal) would average three to four times as high as the first half;

Secondly, and equally important, Because of the very heavy mileage duty, which is at least three times the average of American passenger engines, and four to six times the average of European engines. This heavily reduces the expenses arising from frequent cooling-off of the engine. *Compare the following Table 53.*

Table 53.

Engine Repairs per Mile Run, in Detail, 1868–1875.

Including *both Repairs and Renewals.* Gt. So. & W. Ry. of Ireland (1866–75).

	Engine Only.			Tender.			Engine and Tender.			Percentages.
	Mat.	Lab.	Total	Mat.	Lab.	Total	Mat.	Lab.	Total	
	cts.	cts.	cts.	cts.	cts.	cts.	cts.	cts.	cts.	%
Machinery	.694	1.008	1.702	....	....	....	.694	1.008	1.702	26.1
Drivers and tires (and frames) / Trucks	1.092	.418	1.510	.436	.207	.643	1.528	.625	2.153	(11.3) 29.9 (18.6)
Boilers and flues	1.090	.588	1.678	.070	.060	.130	1.160	.648	1.808	28.1
Wood-work and fittings	.272	.152	.424	.026	.052	.078	.298	.204	.502	8.0
Painting	.118	.130	.248	.040	.065	.105	.158	.195	.353	5.2
Totals, cents per mile	3.266	2.296	5.562	.572	.384	.956	3.838	3.388	6.518	100.0
Percentages	50.2	35.1	85.3	8.8	5.9	14.7	59.0	41.0	100.0	....

Tender repairs were given only in aggregate, and distributed as nearly as might be to the several items in same ratio as above table.

This same table is given in the following Table 55, rearranged so as to give repairs and renewals separately.

134. Repairs of course vary materially with the class of engine, and it would be quite impossible to give exact statistical evidence on this point which could be regarded as satisfactory. It may be estimated, however, with a very considerable degree of certainty, as follows:

About one eighth of the cost of engine repairs is for repairs of tender, which is of course substantially the same for any class of engine. The remaining cost is almost equally divided between material and labor, as will appear from Tables 52–53–55–56. The cost of the labor is but very slightly affected by the weight of the engine and its various parts, although it is so affected to some extent. The cost of material will be nearly in accordance with the weight, but not fully so, many of the more expensive parts being substantially the same on all engines. If, therefore, we say that half the total cost of engine repairs (including the tender) varies with the weight, and half is independent thereof, it will probably be very nearly exact, for engines engaged in the same service, and equally well adapted mechanically for that service. There is no evidence whatever that the heavier class of engines suffer materially in wear and tear from their difference in proportion and design.

Table 54.

Details as to Cost of Locomotive Repairs.

Cost Per Train-Mile of Labor and Material.

English Railways, Average, 1868–75.	Increase per cent in No. of Engines.	Labor.	Mate-rial.	Total.	Per cent of Labor.	Av. Total Cost Repairs for 21 preceding yrs., 1849–69.
	%	cts.	cts.	cts.	%	
London & Northwestern	32.2	3.04	3.10	6.14	49.6	6.90
Midland	73.6	2.65	3.10	5.75	46.0	7.13
Great Northern	8.1	3.12	3.29	6.41	48.7	5.87
Great Western	42.2	3.86	3.58	6.44	60.1	6.73
Lancashire & Yorkshire	47.2	3.05	3.34	6.39	47.6	5.36
Gt. Southern & W. of Ireland	15.0	3.08	3.82	6.90	44.6	....
Average	36.4	3.13	3.21	6.34	49.3	6.40
French.						
Paris & Orleans, 1875	....	1.70	2.32	4.02	42.4	
Paris, Lyons & Med., 1865–74	....	2.00	2.83	4.83	41.6	
Prussian Railways, 1874.	Labor. R'd H'se.	Labor. General.				
State Railways	0.58	1.10	1.70	3.38	50.0	
State Control Railways	1.33	1.16	1.98	4.47	55.5	
Private Railways	0.80	1.03	0.97	2.80	65.4	
American Railways.						
Phila. & R'g (1869–75), repairs only		3.90	2.94	6.84	56.7	
" " (1876–80), " "		2.38	1.93	4.31	(55.)	
" " (1869–75), renewals only		0.81	1.22	2.03	(40.)	
" " (1876–80), " (approx.)		0.60	0.90	1.5	(40.)	
" " total rep'rs and ren'ls ('69–75)		4.71	4.16	8.87	(53.)	
" " " " ('76–80)		2.98	2.83	6.81	(58.4)	

For further notes as to ratio of cost of labor to material, see Index.

None of these figures include *shop and general charges*, maintenance of machinery, clerks, draughtsmen, policing shops, etc., which run about 50 per cent or over of labor account on nearly all railways.

These statistics are supposed to be all *per train-mile*. The ratio of engine-miles to train-miles on English railways is about as 125 to 100—sometimes even 177 to 100. The same holds substantially true of American railways, reported statistics being generally computed per *engine*-mile. A deduction of 15 to 20 per cent from the total cost of engine repairs per train-mile will give the cost excluding switching-engines, which cost much less per mile for repairs than others, on most roads.

TABLE 55.

ENGINE REPAIRS AND RENEWALS IN DETAIL—GT. SO. & W. RAILWAY OF IRELAND (1866–75).

Cents Per Train-Mile.

ITEMS.	LABOR.			MATERIALS.			Grand Total.	Per-cent-ages.
	Re-newals.	Re-pairs.	Total.	Re-newals.	Re-pairs.	Total.		
	cts.	cts.	cts.	cts.	cts.	cts.		
Boiler	.134	(.302)	.436	.656	.290	.946	1.382	21.2
Smoke-box, etc	.112	(.04)	.152	.092	.052	.144	.296	4.5
Wheels, frame, etc	.118	(.30)	.418	.574	.518	1.092	1.510	23.2
Machinery	.258	(.75)	1.008	.190	.504	.694	1.702	26.1
Mountings	.052	(.10)	.152	.154	.118	.272	.424	6.5
Painting	.030	(.10)	.130	.058	.060	.118	.248	3.8
Total Engine	.704	1.592	2.296	1.724	1.542	3.266	5.562	85.3
Tenders	.098	.286	.384	.292	.280	.572	.956	14.7
Total	.802	1.878	2.680	2.016	1.822	3.838	6.518	100.0
Percentages	12.2	28.8	41.0	31.0	28.0	59.0	100.0	...

Credits for old material (amounting, on repairs, to .264 cent; on renewals, to .192 cent—total, .456 cent) are to be deducted from this table for net cost, probably about in the proportion of two thirds for old brass in boiler and one third for other parts.

Proportion of renewals to repairs about normal, for general practice.

The labor on repairs is an approximate distribution where given in brackets, otherwise the distribution is exact.

Round-house repairs constitute over thirty per cent of the labor on repairs proper, or .616 cent per mile.

Under these assumptions we are led to the conclusion that engines of the Consolidation type will cost about 25 per cent more per mile run than the eight-wheel "American" engines, or say 6¼ cents under the most favorable circumstances for repairs and renewals proper. Heavy Mogul or ten-wheel engines, similarly, will cost about one tenth to one eighth more. This estimate is entirely consistent with the as yet fragmentary and imperfect records of experience, but the latter do not exist in sufficient abundance to say that in themselves alone they prove anything.

See foot of page 148.

NOTE TO TABLE 57.—The American statistics (and not the English) show the cost per *revenue* train-mile of *all* engines, including switching.

TABLE 56.

ENGINE REPAIRS AND RENEWALS, PARIS & ORLEANS RAILWAY OF FRANCE (1865–75).

	LABOR.		MATERIALS.		TOTAL.		Grand Total.
	Renewals.	Repairs.	Renewals.	Repairs.	Renewals.	Repairs.	
Engines	.130	.842	.342	1.238	.472	2.080	2.552
Tenders	.040	.370	.106	.540	.146	.910	1.056
Total repairs proper	.170	1.212	.448	1.778	.618	2.990	3.608
Tools and machinery	.074		.094		.168		.168
Clerks and general	.248		...		.248		.248
Total all repair expenses	1.704		2.320		4.024		4.024

The proportion of renewals to repairs in this table, and in less degree the cost of repairs only, is stated to be unduly low, as appears certain from the figures.

TABLE 57.

TOTAL COST, BY ITEMS, OF MOTIVE-POWER.

Cents Per Train-Mile.

		AMERICAN.			Av. of U. S. Census. 1880.	ENGLISH.		
		Penna. R.R. 1879–83.	L. S. & M.S.Ry 1872–81.	Mass. RRs. 1878–81.		Gt. W. Ry. 1869–76.	Gt. So. & W. 1875.	Midl. Gt. W. 1875.
Engine Wages		5.450	5.787	....	7.0	4.66	4.32	3.84
Fuel	Coal	4.705	8.85	10.94	8.4	4.34	6.61	6.50
	Wood	.223						
Maint. Locs.	*Repairs proper*	5.910	5.015	5.02	5.6	Lab. 3.76 Mat. 2.46	2.82 3.80	3.42 2.78
	Mt. shops	.612	....	....		0.22	0.32	....
	" tools and mach'y	.435	....	....				
	Clean'g and polic'g	1.715	.35	....		0.40	0.66	0.20
	Watchmen	.133	....	....				
Stores	Oil	.255	.22	1.11	1.0	0.48	0.66	0.82
	Tallow	.259						
	Waste	.123	.10					
	Other stores	.052						
	Loc. fixtures	.358	....					
Water Supply	Expenses	.602	.6	....	0.6	0.42	0.50	0.32
	Maintenance	.368	....	....		....	....	....
Gen'l.	Taxes	.215	....	....	....	....	....	....
	Stationery	.098	....	....	....	....	....	....
	Incidentals	.415	....	....	....	....	....	....
Total Motive-power		21.928	....	....	22.6	16.74	19.76	17.90

TABLE 58.

COST OF MOTIVE POWER AND CARS ON TWENTY ENGLISH RAILWAYS.

	20 Largest Corporations.	4 Largest Corporations.	Mass. 1878–81.
No. of locomotives	11,005	6,118	....
No. of carriages	33,203	14,902	....
No. of wagons	335,158	171,431	....
Av. mileage per year per engine	17,064	16,520	....
Cost of working	12.46 cts.	12.94 cts.	....
" engine repairs	6.17 "	6.90 "	....
Total motive-power	18.63 cts.	19.84 cts.	....
Cost of carriage repairs	2.58 cts.	2.28 cts.	....
" wagon "	3.88 "	3.98 "	....
Total cost locs. and cars	25.09 cts.	26.10 cts.	....
Cost per engine per year	$1,086	$1,148	$1,108
" carriage per year	133	160	370
" wagon per year	23.41	20.80	55.40

English carriages and wagons may be considered, without important error, to have half the weight, capacity, and cost of American rolling-stock. See Index.

In answer to inquiry as to experience and practice with Consolidation engines on the Pennsylvania Railroad, the writer was informed as follows by Mr. T. N. Ely, Supt. of Motive-Power:

"1. Consolidation locomotives are not much harder on curves than other locomotives, we think.

"2. The comparative cost of repairs per hundred miles between a Class I locomotive (Consolidation type) and a Class D (ten-wheel) locomotive is about as follows:

"Class I	4.87
"Class D	4.50
Difference,	0.37

or nearly eight per cent against the Class I."

This percentage of difference, although founded on much experience, must, it would seem, somewhat underrate the normal difference.

Passenger engines, as a general rule, cost about twenty per cent less for repairs than freight engines, or about four cents per mile under the most favorable conditions.

TABLE 59–60.

MINOR DETAILS AS TO LOCOMOTIVE REPAIRS.

Detail items, Gt. S. & W. Ry., Ireland. (Condensed in Table 55.)	CENTS PER TRAIN-MILE. Rep'rs.	Ren'ls.	Total.
Copper plates	.052	.162	.214
" stays	.020	.034	.054
" tubes	.062	.200	.262
Fire-bars and brick arch	.128	.260 (Fire-bars, arch and Boiler sundries)	.416
Boiler sundries	.028		
Total *Boiler*	.290	.656	.946
Smoke-box and platform	.052	.092	.144
Wheels	....	.164	.164
Axles	.114	.128	.242
Tires	.198	.128	.326
Springs	.138	.062	.200
Sundries	.068	.092	.160
Total *Running G'r*	.518	.574	1.092
Cylinders	.048	.058	.102
Axle-boxes	.078	.132 (Axle-boxes to Machinery sundries)	.590
Axle-brasses	.052		
Big-end brasses	.010		
Pistons, etc	.034		
Glands and bushes	.042		
Slide-valve castings, brass	.034		
Eccentric liners	.054		
White metal	.080		
Machinery sundries	.070		
Total *Machinery*	.504	.190	.694

Detail items, Gt. S. & W. Ry., Ireland. (Condensed in preceding table.)	CENTS PER TRAIN-MILE. Rep'rs.	Ren'ls.	Total.
Mountings	.118	.154	.272
Clothing, painting, etc	.060	.058	.118
Total *Engine*	1.542	1 724	3.266
Tender	.280	.292	.572
Engine and tender	1.822	1.870	3.838
Less *credits*	.264	.192	.456

Labor acct., as distributed in detail to general items in Table 55:

	Rep'rs.	Ren'ls.	Total.
Labor, r'd-h'se rep'r.	.616	.704 (r'd-h'se and shop)	2.296
" shop "	.976		
" tender "	.286	.098	.384
Total Labor	1.878	.802	2.680

Proportion of round-house repairs, Phila. & Erie R.R., about the same, viz.: 26 per cent of labor.

See also Table 136.

TABLE 61.

COST OF MAINTENANCE OF TIRES IN DETAIL, GT. S. & W. RY.

Cents Per Train-Mile.

DATE.	ENGINES. Pass.	Freight.	All.	Tenders.	Total.
1860–64	.33	.57	.42	.24	.66
1865–69	.44	.46	.45	.15	.60
1870–74	.22	.44	.30	.23	.53
Average	.33	.49	.39	.21	.60

Mileage of Tires,	4′ 6″	6′ 6″
Iron,	52,300	114,500
Steel,	105,700	196,600

TABLE 62.

COST OF NEW LOCOMOTIVE IN DETAIL—CHICAGO, BURLINGTON & QUINCY LOCOMOTIVE, CLASS A (PASSENGER).

See also Table 131.

	Smith Shop.	Machine and Vice Shop.	Erecting Shop.	Boiler Shop.	Cooper and Tin Shop.	Carpenter and Paint Shop.	Car Dep't. Smith, Carp., and Mach.	Totals.		Total.	Percentages.		
								Labor.	Material.		Labor	Material.	Total.
	$	$	$	$	$	$	$	$	$	$	$	$	$
Boiler	33	60	72	400	6	......	......	571	1,474	2,045	9.8	25.3	35.2
Machinery	87	373	143	1	11	2	......	617	409	1,026	10.6	7.1	17.7
Running gear	58	49	72	......	......	......	4	183	625	808	3.3	10.7	14.0
Frames	67	56	......	......	......	......	......	123	119	242	2.1	2.1	4.2
Fittings	31	120	......	40	38	13	63	305	587	892	5.3	10.1	15.2
Painting	......	......	......	......	......	53	......	53	29	82	0.9	0.5	1.4
Total engine	276	945	......	441	55	68	67	1,852	3,243	5,095	32.0	55.8	87.8
Tender	4	17	......	130	......	6	44	201	507	708	3.5	8.7	12.2
Total eng. and tend.	280	962	......	571	55	74	111	2,053	3,750	5,803	35.5	64.5	100.

Total amount brass castings, 1,698 lbs.
Total amount cast-iron, 31,848 lbs.
Total amount truck wheels (12), 5,640 lbs.
Total amount smith-furnace coal used, 36,000 lbs.

TABLE 63.

COST IN DETAIL OF A PENNSYLVANIA CLASS C (BITUMINOUS PASSENGER) ENGINE.

Gt. So. & W. Ry. of Ireland:	Fitters and apprentices,	81 to 85 c. = 82½ c.	Av. of all classes of labor on engine, say $0.90.
	Turners' " "	83 to 101 c. = 92 c.	
Av. rates of pay..........	Boilersm. " "	81 to 85 c. = 82½ c.	
	Fitters' laborers,	53½ to 56 c. = 54 c.	
	Smiths.	101 to 104 c. = 102½ c.	

Av. pay to *skilled mechanics only*, $1.25 to $1.35.

NOTE.—The discrepancies between the above detailed costs of engines in Tables 63 and 62 cannot be reconciled. It is doubtless in part due to difference in price of materials, but nevertheless the charges for the C., B. & Q. engine seem very low on materials, while on the Class "C" Penna. RR. the cost seems unduly high, especially on the tender. The sum of $200 out of $425 for "tender tank," and some other items, have been transferred from material to labor in preparing the above statement, which therefore differs by that sum from the published statement in Dredge's "Pennsylvania Railroad." Compare the following abstract of Class "I."

TABLE 64.

COST OF A PENNSYLVANIA RAILROAD "CLASS I" (CONSOLIDATION) ENGINE.

	Material.	Labor.	Total.
Boiler..................	$1,877		
Machinery...............	935		
Running gear..........	1,456		
Frames..................	200		
Fittings.................	652		
Painting................	47		
Total engine..........	$5,167		
Tender...................	845		
Tot. engine and tender.	$6,012	$3,968	$9,980
Phila. & Reading, 1881, average of 18 engines..			$10,370

See also Table 134.

TABLE 65.

RATIO OF COST OF MATERIALS TO TOTAL COST FOR BOTH NEW ENGINES AND REPAIRS.

ON NEW ENGINES (OR RENEWALS).		ON REPAIRS ONLY (*ex* RENEWALS).	
Chicago, B. & Q. RR., Class A.......	64.6%	New York Cent. & H. R. RR.... ..	44.0%
Pennsylvania " " C.......	66.7	Philadelphia & Reading........	43.3
" " " I.	60.3	Av. of U. S., *repairs only*...........	Abt., 44
English (R. Price Williams)..........	78.1	" " *repairs and renewals*..	" 50
Gt. So. & W. of Ireland..............	72.9	Gt. So. & W. of Ireland..............	45.3
" " " renewals......	69.5	" " av. repairs and renewals.	55.8
Paris & Orleans......................	71.8	Paris & Orl., " " " " .	58.0

135. The apparent cost of repairs has been kept down on all our railways for the time being by the constant additions of new stock, thus greatly reducing the percentage of renewals and heavy repairs. Table 51 will show to what a very important effect this cause must have contributed to reduce the apparent average, especially during the rapid growth of traffic of the last ten years.

136. The distribution of the cost of repairs to the various parts of the locomotive concerns us quite as much as its total amount. Information on this head is somewhat difficult to procure, as, so far as the writer knows, no American railways publish such statistics in a complete form, and few take much trouble to collect the information. Tables 53 to 67, however, give the cost of new "American" engines in detail, and also very full statistics of the cost of engine repairs and renewals on English railways, which latter are undoubtedly substantially accurate, and (with proper allowances) of general application to all railways.

137. From these data we may conclude that, with no very great fluctuations, the total cost chargeable to repairs of engines, including renewals, may be distributed about as follows:

The boiler and its attachments require about	20	per cent
The running gear and frame (of which the frame consumes very little, say 2 per cent),	20	per cent
The machinery proper,	30	"
The mountings, fittings, and painting,	12	"
The smoke-box and attachments,	5	"
Total of engine,	87	per cent
The running gear of tender,	9	"
Tank and body of tender,	4	"
Total,	100	per cent

138. Maintenance of shops, tools and machinery, and other miscellaneous motive-power expenses do not usually appear, as before stated, in statements of the cost of repairs or of running engines, although they constitute a legitimate addition thereto. On the Pennsylvania (Table 57) these items, including stationery, incidentals, and watchmen, but not including the item of "laborers,"—the latter doubtless largely for cleaning engines,—amount to twenty-five per cent of the cost of engine repairs, or about 1¼ cents per train-mile, and the item of "laborers" to as much more. This is higher than is usual, or perhaps it would be more proper to say

that it is based upon a closer apportionment than is usual, many lines having items of a general character for laborers, clerks, etc., to which all such are charged for the whole road, without separately apportioning them to motive-power and other departments.

139. Maintenance of tools, shops, machinery, and other miscellaneous and indirect motive-power expenses, average as nearly as may be 1 to 1½ cents per train-mile on the larger and more important roads, ranging considerably higher on smaller roads, if all the expenses are apportioned with equal care.

This is an expense which is affected but slightly by very considerable variations in engine-mileage, and hence ought to be kept separate from engine repairs proper, but rarely is. It is an important element in the total cost of motive-power.

140. Oil, waste, and small engine supplies cost on an average about one cent per mile, but often run as low as half a cent, or even less, on the

TABLE 66.

PERCENTAGES OF THE COST OF LABOR AND OF MATERIAL, AND OF THE VARIOUS PARTS OF NEW LOCOMOTIVES.

(Shop and general expenses not included, amounting to about 50 per cent of Labor Account.)

ITEMS. (For amounts see Tables 61, 62, etc.)	C., B. & Q. RR. (CLASS H). St'd Freight.			PENNA. RR., "C." St'd Passenger.			PENNA. RR., "I." St'd Freight.		
	Lab'r	Mat'l	Total	Lab'r	Mat'l	Total	Lab'r	Mat'l	Total
Boiler and braces	9.8	25.3	35.1	7.4	20.6	28.0	(11.0)	18.8	29.8
Machinery	10.6	7.1	17.7	9.9	10.4	20.3	(12.0)	9.4	21.4
Running-gear	3.3	10.7	14.0	2.1	13.9	16.0	(4.0)	14.6	18.6
Frame and bed-casting	2.1	2.1	4.2	2.2	2.1	4.3	(2.2)	2.0	4.2
Fittings and pump, cab, etc.	5.3	10.1	15.4	5.5	7.4	12.9	(5.0)	6.5	11.5
Painting	0.9	0.5	1.4	0.9	0.6	1.5	(1.0)	0.5	1.5
Total engine	32.0	55.8	87.8	28.0	55.0	83.0	(35.2)	51.8	87.0
Tender	3.5	8.7	12.2	4.6	12.4	17.0	(4.6)	8.4	13.0
Total engine and tender	35.5	64.5	100.0	32.6	67.4	100.0	39.8	60.2	100.0
Reported cost labor and mat'ls.	$5,803			$7,954			$9,980		
Cylinders and weight (long t'ns)	17X24			17X24—33.8 tons.			20X24—40.9 tons.		

TABLE 67.

PERCENTAGES OF COST OF VARIOUS PARTS FOR VARIOUS FOREIGN LOCOMOTIVES.

(For American, see preceding table. See also Table 131.)

W.
I).
ght.

Reported cost, labor and materials	$9,690	
Cylinders and weight (long tons)	(17×24)—29.5 tons	... tons.
Approx. increase per cent in cost, due to.	brass in b'r 16.0% wr't-i. wh's 11.6%	10.0% ..12.8%

ITEMS.	GT. SO. & W. (Ireland). Heavy Passenger.			GREAT WESTERN RAILWAY (England). Heavy Passenger			St'd Freight.		
	Lab'r	Mat'l	Total	Lab'r	Mat'l	Total	Lab'r	Mat'l	Total
Boiler	5.0	23.3	28.3	3.8	25.0	28.8	4.1	24.6	28.7
Wheels, frame, etc.	4.5	28.5	33.0	5.6	19.4	25.0	5.7	16.0	21.7
Machinery	10.4	7.4	17.8	4.9	3.4	8.3	4.9	3.2	8.1
Smoke-box	5.1	3.8	8.9						
Mountings	1.9	6.0	7.9	9.4	11.0	20.4	9.6	10.4	20.0
Painting	1.6	2.5	4.1						
Total engine				23.7	58.8	82.5	24.3	56.2	80.5
Tender				5.8	11.7	17.5	6.5	13.0	19.5
Total engine and tender. . .	28.5	71.5	100.0	29.5	70.5	100.0	30.8	69.2	100.0
Reported cost, labor and mat'ls	$9,072			$7,432			$6,709		
Cylinders and weight (long t'ns)	(17×23)—30.3 tons.			17×24—31 tons.			17×24—30.5 tons.		
Approx. increase per cent in cost, due to	brass in b'r 8.0% wr't-i. wh's 13.3%			... 5.0% 10.0%			. 5.0% 10.0%		

The distribution to items is not precisely identical in these tables, as will be apparent from the percentages. Multiplying any percentage by the total cost gives the absolute expenditure for the item.

larger roads, especially where there is an independent account kept with each engine.

141. Water-supply costs about half a cent per train-mile as an average, sometimes running below that on roads of very heavy traffic, but oftener running nearer to one cent per mile. On all but roads of very considerable traffic one cent is the safer estimate. The quantity used is very considerable. About six or six and a half pounds of water, as an average, is evaporated per pound of coal, and a freight engine burning a hundred pounds of coal per mile will use some eighty gallons of water, or require the refilling of a 2400-gallon tank within thirty miles at the utmost, as an average. Practically, the consumption of water, as of coal, is irregular, and a full tank may in cases be used up within fifteen miles; requiring, for practical convenience, tanks every ten miles, which is the average on roads of thin or average traffic. On lines of heavy traffic, tanks are placed at average intervals of hardly more than five or six miles. Table 57 gives considerable data as to these minor items.

142. Switching engines constitute an enormous proportion of the total number in service on most roads, the average of the whole State of New York being twenty-eight per cent of the whole number in service, or nearly forty switching engines for every hundred in through service earning money. Their "mileage" is fixed by an allowance (usually six miles per hour, but sometimes eight), so as to bring their expenses per "mile" in some reasonable or desired ratio to that of through engines. The great expense of this service does not tend to decrease, but rather to increase, with growth of traffic, and is with reason felt to be largely due to removable, and hence discreditable, defects of administration. The burden is somewhat relieved at the larger terminals by fixed terminal charges allotted out of the through rates before dividing it (at New York four to five cents per hundred pounds out of through rates of twenty to thirty cents, or even less). It is a charge but little affected by any of the details of alignment, so that we need not discuss it in detail, but in certain computations it is an element which needs to be remembered—notably in computations of the value of reducing grades on old roads, whereby this portion of the motive-power expenses is not seriously reduced.

The diagram given in Fig. 4 illustrates very fairly the past tendency of locomotive expenses. Alone of all the items, wages, it will be seen, have remained practically uniform. There was a slight tendency to decrease during the hard times of 1877–79, but they recovered later, and remain at the end substantially what they were in the beginning.

The cost of fuel declined sharply after 1872, but since 1876 has been nearly

FIG. EXPENSES, C., B. & Q. R. R.

uniform. Two possible causes for this are indicated on the diagram, both of which probably had their effect. One was the increase in miles operated, which probably gave better access to coal-mines, but another and probably very important contributing cause was the increase in miles run per engine per year, which likewise began simultaneously, and ceased to advance sharply after the cost of fuel ceased to decrease.

The course of cost of repairs is very instructive. It will be seen that the decrease has been enormous, and it is, doubtless, in great part due to natural and permanent causes, such as the decrease in cost of materials and better shop facilities. But it needs but a brief glance at the line showing "Number of engines on road," in connection with the cost of repairs, to detect another explanation, of vast importance in its effect on operating expenses, which is too little remembered in studying maintenance charges, viz., the enormous and continuous infusion of "new blood" into the locomotive stock, giving at all times a very large number of new locomotives in the stock *in addition* to the proportion naturally required to replace old engines worn out. As new engines cost comparatively little for repairs, it is inevitable that this abnormal proportion of new engines should greatly affect the average cost of repairs, and it is very clear that it did so. The very small expense for repairs in 1875–9 was not wholly due to economies enforced by hard times, although no doubt largely so, but in great part to the fact that there was a greater proportion of new engines in service than at any time before or since. Afterwards the inevitable increase came about, in spite of heavy falls in the cost of much of the material used, due to improved processes of manufacture and cheaper transportation, and should the continual additions of new stock cease, it is very certain that the increase must go still further. It is to be remembered also that these nominal "repairs" do not include many incidentals for maintenance of shops, etc., which are really a part of the cost of repairs, but not ordinarily included in it. A chief reason for the heavy decline since 1866 is undoubtedly the continued improvement in the character of the road-bed and in the quality of the workmanship and material used.

The increase in the average miles run per engine shows an unusually favorable record, and one not likely to be much further improved on, since an *average* of nearly a hundred miles per day for every day in the year and for all engines nearly reaches the possible limit. It implies that single engines have more than doubled this. The decrease in miles run and simultaneous increase in cost of repairs per mile run in 1882 can hardly be an entirely accidental coincidence.

Table 68 shows the average miles run per year and the average cost per year of "locomotive power" (repairs, stores, wages, and fuel) on ten representative English and American lines. The latter by no means represent the best American practice, as will be evident from Fig. 4, but are those lines (for

the most part) which are operated under the most fairly comparable conditions with the English lines. Could the ton-miles and passenger-miles per year per engine be compared, the contrast in work done per engine would be astounding (over three to one), but the English railway statistics, alone of those of civilized countries, do not give these facts. In part the difference in work done is explicable by difference of conditions, but by no means wholly so.

Table 69 gives the work done per year per engine and the number of engines in all countries, from which it appears that, far as American practice is ahead of English, the latter surpasses that of all other countries.

TABLE 68.

ANNUAL AVERAGE EXPENDITURE PER LOCOMOTIVE FOR LOCOMOTIVE POWER ON TEN LEADING LINES IN THE UNITED KINGDOM AND IN THE UNITED STATES, WITH THE AVERAGE ANNUAL NUMBER OF TRAIN-MILES RUN PER ENGINE.

[Abstracted and recomputed from "Railway Problems," by J. S. Jeans, Secretary British Iron and Steel Association.]

ENGLISH LOCOMOTIVES.			AMERICAN LOCOMOTIVES.		
ROAD.	PER LOCOMOTIVE.		ROAD.	PER LOCOMOTIVE.	
	Average Annual Expenditure.	Average Train-Miles.		Average Annual Expenditure.	Average Train-Miles.
Great Northern	$3,320	21,518	Boston & Albany	$7,240	20,000
North-Eastern	3,540	16,240	Boston & Lowell	8,600	25,000
Midland	3,040	19,600	Boston & Maine	6,640	21,000
London & North-Western	2,455	15,422	Boston & Providence	6,840	18,000
Great Western	3,000	19,313	Old Colony	6,440	20,000
Great Eastern	3,720	21,456	N. Y., New Haven & H.	8,610	31,000
Caledonian	2,980	18,101	N. Y., Lake Erie & W'n.	4,260	14,000
North British	2,610	19,959	N. Y. Cent. & Hudson R.	7,720	25,000
London & South-Western	4,370	22,323	Pennsylvania—Pa. Div.	5,880	26,000
Lond., Bright. & So. C'st	3,610	19,844	Baltimore & Ohio	2,700	27,000
Average	$3,080	17,539	Average	$5,590	23,928

Average earnings per year per locomotive	American	$14,860
	English	$10,940
Average rate per ton-mile	American	1.057 cts.
	English	2 to 2.4 cts.
Average rate per passenger-mile	American	2.198 cts.
	English (about the same).	

All the above is for 1883, except the rates, which are for 1885. The earnings and rates given are for the national aggregates, and not merely for the ten roads above.

TABLE 69.

TOTAL NUMBER OF LOCOMOTIVES IN DIFFERENT COUNTRIES, NUMBER OF TRAIN-MILES WHICH THEY HAVE ACCOMPLISHED, AND THE AVERAGE MILES PER DAY AND PER YEAR PER LOCOMOTIVE.

[Abstracted from "Railway Problems," by J. S. Jeans, Secretary British Iron and Steel Association, with some modifications.]

COUNTRIES.	Number of Locomotives.	Train-Miles. 1 = 1,000.	Average Miles Per Locomotive Per Annum.	Average Miles Per Locomotive Per Day.
United States.....	23,823	538,011	22,583	62
United Kingdom..	14,827	272,803	18,395	50
Germany.........	11,330	134,489	11,870	33
Austria...........	3,671	47,144	12,842	35
Belgium..........	1,790	23,870	13,335	37
France......... ...	8,088	135,860	16,798	46
Italy.............	1,630	24,642	15,118	41
Luxembourg......	34	433	12,735	35
Norway..........	111	1,557	14,027	38
Netherlands......	519	11,435	22,033	60
Roumania........	211	2,207	10,460	29
Russia...........	5,844	61,940	10,599	29
Finland..........	98	1,177	12,010	33
Switzerland.......	595	7,674	12,897	35
India............	1,730	33,919	19,606	54

The above statistics are for 1883 for the United States and Great Britain, and for 1882 for the other countries. Some American roads (see Fig. 4) run up to an average for large numbers of engines of 100 miles per day.

143. REPAIRS OF CARS can be estimated with most correctness per car-mile, and not per train-mile. They may be roughly placed, with a very fair degree of correctness, at $\frac{1}{8}$ cent per freight car-mile and $1\frac{1}{2}$ cents per passenger car-mile, on the larger roads. On small roads $\frac{1}{2}$ cent per car-mile for freight-car repairs is more nearly correct. Figures indicating much less than this require allowances. This, however, as in the case of engine repairs, includes only labor and material directly applied to the cars themselves, and there is a considerable amount of incidental expenditure, which is really a part of the actual cost of maintaining the cars, but which is yet, for very proper reasons, already stated, not generally included in the reported cost of car repairs.

Such general and incidental expenses amount to from 10 to 25 per cent of the total cost of car repairs proper.

TABLE 70.

AVERAGE COST OF CAR REPAIRS ON WESTERN & ATLANTIC RAILROAD FOR DIFFERENT KINDS OF CARS.

Cost Per Car Per Year.

	Passenger.	Local Box.	Stock.	Coal and Flat.	Line.
Running gear	$64.80	$6.78	$7.46	$6.76	$19.09
Interior fittings	23.45	......	......	......	......
Miscellan's material	41.75	12.10	8.50	6.50	13.49
Total material	$130.00	$18.88	$15.96	$13.26	$32.58
Labor	111.50	11.12	9.35	4.48	10.62
Total	$241.50	$30.00	$25.31	$17.74	$43.20
Miles per car	36,480	7,780	5,601	5,420	10,043
No. of cars in use	138	194	40	489	648

Cost Per Car Mile.

	cts.	cts.	cts.	cts.	cts.
Running gear	.178	.087	.133	.125	.191
Interior fittings	.064	......	......	......	......
Miscellan's material	.114	.155	.152	.120	.135
Total material	.356	.243	.285	.245	.326
Labor	.306	.143	.167	.083	.106
Total	.662	.386	.452	.328	.432

The above includes, whether by chance or otherwise, no charges whatever for seats or upholstery of passenger cars. Otherwise it includes all work done in the car department for maintenance of cars, both repairs and renewals. The cost per passenger car is very low.

Tables 70, 71, 72, 73 were computed from data given in a very careful paper on car mileage and repairs by E. C. Spalding, Car Accountant W. & A. R. R., and afford about the most trustworthy data on the details of car repairs which is extant. Such information is very difficult to obtain, and even this affords no means of distributing expenses to different parts of the car body. Making a proper allowance for labor, it will be seen that somewhat over 40 per cent of car repairs arises from running-gear maintenance, and nearly 75 per cent from truck repairs. By far the larger part of the remainder is for draw-gear repairs. Other repairs of body are a very small expense.

These statistics give the true average cost of car repairs for a stock which

is being neither increased nor decreased. They are almost the only records of the kind which have been published.

One very notable fact in Table 70 is that, contrary to what might be expected, the cars which make the largest mileage per year cost the most per mile for maintenance. The chief reason for this is, probably, that they are maintained up to a higher standard; but as the cars in local service are (1) subjected to more banging and more frequent use of brakes, and (2) make a smaller mileage per year, so that the rotting and other effects of time and age are divided up among a smaller number of miles, we should expect to see a somewhat higher cost per mile run for such cars. On the contrary, it is smaller, both for running gear only and for the aggregate of all items.

Table 74 gives the cost of car repairs on the Lake Shore & Michigan Southern Railway for repairs proper and renewals separately. In former years the cost of Lake Shore car repairs was much higher than that shown; $50 per year is perhaps a fair permanent average at present prices. The reason why no distinction is even attempted between renewals and repairs in either locomotive or car maintenance is clear from the note to the table.

TABLE 71.

COST OF FREIGHT-CAR REPAIRS PER MILE RUN BY ITEMS FOR CARS OF VARIOUS AGES—WESTERN & ATLANTIC RAILROAD.

Items.	Box Cars.				Coal Cars.			
	Av'ge all Cars.	1 to 5 years.	6 to 10 years.	11 to 16 years.	Av'ge all Cars.	1 to 5 years.	6 to 10 years.	11 to 16 years.
Axles	.035	.022	.042	.051	.031	.016	.045	.034
Brasses	.101	.081	.112	.123	.073	.042	.099	.083
Wheels	.073	.052	.077	.110	.063	.032	.091	.071
Running gear	.209	.155	.231	.284	.167	.090	.235	.188
Cast-iron	.030	.020	.030	.050	.032	.021	.031	.043
Wrought-iron	.054	.036	.066	.074	.070	.028	.100	.086
Lumber	.052	.017	.073	.090	.065	.007	.116	.081
Springs	.021	.022	.020	.022	.011	.011	.006	.014
Bolts	.022	.017	.022	.033	.016	.016	.018	.016
Paint	.009	.002	.016	.011	....	....	....	....
Labor	.135	.075	.154	.227	.141	.046	.220	.170
Nails, chains, and metallic sundries	.012	.007	.018	.013	.004	.002	.005	.006
	.544	.351	.630	.804	.506	.221	.731	.604
Av. miles run per year	9,238	11,767	8,904	6,996	4,970	5,541	4,336	5,091
Av. total cost per year	$50.33	$39.82	$56.10	$56.26	$25.24	$12.25	$31.67	$30.72

TABLE 72.

COST OF NEW BOX CAR IN DETAIL, 1883.

[Deduced from data given in a paper by E. C. Spalding, Car Accountant, Western & Atlantic Railroad.]

Material.		Labor.		Total.	Per Cent.
Lumber.... .. .3,987 ft.	$79.74	20 days carpenter.	$45.00	$183.33	36.1
Wrought-iron...704 lbs.	35.20				
Cast-iron... ....606 "	18.18				
Nails, etc..............	5.21				
Draw-springs. ..46 lbs.	4.14	....	....	4.14	0.8
Tin roof	12.60	4 days tinner.......	4.00	16.60	3.3
Painting...............	3.28	1½ days painter.....	3.00	6.28	1.2
Total body...........	$158.35	....	$52.00	$210.35	41.4
P. c. of total cost.....	31.2	....	10.2	41.4	
TRUCK.					
Wheels........4,200 lbs.	$160.00	....	....	$160.00	31.5
Axles.........1,400 "					
Brasses... ... 64 "	14.08	....	....	14.08	2.8
Springs....... 184 "	16.56	....	....	16.56	3.3
Lumber..........487 ft.	9.74	Carpenter	$5.65	104.57	20.7
Wrought-iron.1,000 lbs.	50.00				
Cast-iron......1,306 "	39.18				
Painting.....	.79	Painter.............	.50	1.29	.3
Total truck....	$290.35	....	$6.15	$296.50	58.6
Total car.............	$448.70	....	$58.15	$506.85	100.0
Per cent..............	88.5	....	11.5	100.00	

The weight of metal in a standard New York Central 40,000-lb. box-car is given as follows :

Wrought-iron in car body	2,552	lbs.
Cast-iron in "	797	"
Steel in "	104	"
Malleable iron in "	13¼	"
Wr't-iron in trucks, includ'g axles,	3,144	"
Cast-iron in trucks, includ'g wheels,	5,366	lbs.
Malleable iron in trucks...........	48	"
Journal-bearings....................	80	"
Wheels, each....	525	"
Axles (M. C. B. Standard)..........	347	"

THE TOTAL COST PER TRAIN-MILE of passenger-car repairs and freight-car repairs is very nearly the same in the aggregate, as may be seen from Tables 75–80, although the proportion of the constituent elements differs considerably. (See par. 150.)

146. The repairs which the road using foreign cars has to pay for in addition to paying $\frac{3}{4}$ cent per mile are not of great importance, and are determined in this wise: At every junction point there is an inspector, usually a joint inspector, who admits cars on to the road only when "in good running order," as determined by minute specifications revised yearly by the Master Car-Builders' Association. Once on the road it must be passed off as fulfilling all the same specified conditions, or be sent to the shop for repairs. Failures of the wheels or axles are assumed to be (in default of evidence to the contrary) from the normal wear paid for by the $\frac{3}{4}$ cent per mile. Other failures, broken draw-timber castings, sills, doors, roofs, trucks, etc., are assumed to result from bad usage, and are made good in addition to the mileage payments. In this way a road may often have to pay for repairs due to gradual deterioration, for which it is not at fault; but the average is about fair: and since no general repairs are made, but the car is simply patched up so as to barely pass inspection, it does not amount to a very heavy addition to the established mileage rate.

147. The apparent cost of car repairs, to an even greater extent than the cost of engine repairs, has been and will continue to be far smaller than it really is because of the constant additions of new stock, made necessary by the rapid growth of traffic. As the repairs on new cars are small for many years, if the stock of cars be doubling every four or five years, as has been the case in the United States for the past twenty years, the apparent cost of repairs cannot but be greatly affected. Table 74 shows how great an effect this cause may have, in many cases. Any figures seeming to be much below those here given will be apt to be largely affected by this cause, or by the one above alluded to—omission of general and incidental shop expenses.

148. We are less concerned, however, as in the case of engine repairs, with the total cost of car repairs than with its origin and subdivisions; as in that way only can we properly determine what effect differences of grade and line, or other specific causes, will have upon the cost of this item. Few railways keep, and none publish, any detailed record of the cost of the various items which make up the enormous aggregate of "repairs of cars," that being the only one which appears in the reports, or, as a rule, on the books. It is therefore difficult to determine precisely the ratio of the various items to each other. Nevertheless, from the information given in Tables 70 to 73 and other data (compare especially Table 87) we may conclude that the actual **cost of repairs and renewals of freight cars is divided very nearly as follows:**

Wheels,	30	per cent.
Axles, brasses, and axle-boxes,	30	"
Springs,	10	"
Truck frame and fittings,	5	"
Total truck,	75	"
Brakes,	5	"
Draw-bars,	10	"
Sills and attachments,	5	"
Car body, painting, etc.,	5	"
Total,	100	"

149. Passenger-car repairs are, for wheels, axles, and brasses, but slightly more than for a freight car per mile. Exact information as to the comparative mileage of passenger and freight wheels is difficult to obtain, owing to the fact that as soon as wheels show any noticeable defect, which yet does not make them unsafe, they are withdrawn from passenger service and put under freight cars, often making a large mileage before being finally scrapped. The general tendency of the available evidence is that there is but little difference, and that difference in favor of passenger cars, the effect of the higher speed being counterbalanced by less injurious brakes and better springs. The extra cost of repairs and renewals of passenger cars is mainly in its decorations, better painting, and interior fittings; and bearing in mind that passenger cars are not exposed to anything like the rough service, blows, and shocks which come upon freight cars, we may say, without any error of moment, that the average cost per passenger car-mile is about as follows:

	Frt. Car. Cts. Per Mile.	Pass. Car. Cts. Per Mile.
Running gear, draw-bars, etc.,	0.3	0.5
Sills, frames, etc.,	0.1	0.2
Painting and varnishing car body,	...	0.2
Interior fittings and upholstery,	...	0.5
Total,	0.4	1.4

150. In other words, the cost of maintaining a passenger car for those items or parts of items which are affected by differences of distance, curvature, and gradients is not so much greater than for freight cars, but

that it is noticeably smaller per passenger train-mile, but the TOTAL cost of repairs per train-mile is about the same. (See note foot of page 163.)

151. The average mileage of freight cars per year, taking the whole equipment of a road together, ranges from 11,000 to 15,000 miles, sometimes even higher, but very frequently considerably less. On short roads with heavy local business it is often smaller than this, averaging 10,000 miles per year, or even less. The tendency in recent years has been to decrease. The mileage made by different cars, however, varies enormously: "line" cars, so called, belonging to the independent or semi-independent organizations, which now conduct a very large proportion of the through-freight business passing over several lines, make the greatest mileage, as is but natural; both because they are exclusively used in long-trip through-business and because they are most sharply looked after. The general average of all classes of cars (see also Table 70) is about as follows:

	Miles Per Day.	Miles Per Year.
Coal and flat cars, ...	15 to 20	5,000 to 7,500
Box cars, ...	25 to 40	9,000 to 15,000
"Line" cars, ...	70 to 100	25,000 to 35,000
Average, ...	35 to 45	12,000 to 16,500

The average mileage of passenger cars ranges from 40,000 to 60,000 miles per year, these being about the two extremes. Through-coaches, sleeping-cars, etc., run much higher than this—up to, in some cases, 150,000 miles, averaging about 100,000.

152. TRAIN WAGES, the sole remaining considerable item affected by line and grades, are less difficult than the preceding to state with correctness. The following are a close approximation to the rates which now prevail in this country for average runs of a hundred miles. In 1870–74 they were naturally higher than this, say 25 per cent, and higher yet in the preceding decade. In 1875–78 they were about 10 per cent lower. They vary considerably in different parts of the country, but less than any other item of train expenses:

	Freight.	Passenger.
Engineman, ...	$3.50 to $3.75	$3.50 to $4.00
Firemen, ...	1.75 to 2.00	1.75 to 2.00
Conductor, ...	2.75 to 3.00	3.75 to 5.00
Brakeman (each, $1.75).	3.50 to 5.25	3.50 to 3.50
Baggage-men, ...	... ...	2.00 to 3.00
	$11.50 to $14.00	$14.50 to $16.50

153. The system by which train wages are fixed varies materially. It is sometimes strictly by the month or day, especially in passenger service—a certain run being called a day's work, independent of the time actually employed. These runs may vary anywhere from 75 to 110 or 120 miles; but if it constitutes *de facto* a day's work, it is rated a day, independent both of time and distance run.

This system was formerly universal, and is still very common for passenger service; but with increase of traffic, and especially with the consolidation of lines into great systems, with runs of widely varying length, the practice is coming more and more into vogue of paying strictly according to mileage, in the manner specified in par. 191. The chances are that the tendency to pay in close accordance with mileage will become stronger and stronger with the great organizations, especially in freight service, while the former plan will always prevail with the smaller independent lines, and even on many of the larger lines for passenger service.

154. A compromise plan, intermediate between these two extremes, is at present more usual than any other. The runs over various divisions are graduated as 1 day, $1\frac{1}{8}$ day, $1\frac{5}{16}$ day, sometimes, though rarely, $\frac{7}{8}$ day, etc., etc., so as to have a close correspondence with the real distance, but not to be in exact ratio thereto; other circumstances, such as number of stops, etc., being often taken into account. This appears to be not only fairer than an exact mileage basis, but more acceptable to employés. The present system of handling traffic, by which the freight crews not only know no distinction of night or day or week-day and Sunday, but do not even recognize the day of twenty-four hours, tends to facilitate this basis of payment; the crews being "on" or "off" at intervals determined by the pressure of traffic, and not at all by the number of hours in the day or days in the week. In passenger service, or wherever the freight service is tolerably regular in its character, the deference paid to an exact mileage basis is much less marked. (See also par. 191.)

155. The tendency is strong to increase the length both of locomotive runs and of divisions. Locomotive runs were formerly from 80 to 100 miles. At present they range by preference from 120 to 150 miles, the gradients being often, of course, a controlling condition. The prevailing tendency is well illustrated by the locomotive divisions on the Canada Pacific, of which there are 19 on the 2445 miles between Montreal and the Pacific, an average run per locomotive of $128\frac{3}{4}$ miles. The shortest and longest runs are: (See page 178.)

TABLE 75.

DETAILS OF EXPENSES AND TRAFFIC OF THE RAILWAYS OF THE UNITED STATES AND OF VARIOUS SECTIONS THEREOF.

[Computed from the Statistics of the Census of 1880.]

CENSUS GROUPS OF STATES.	Total U. S.	New England. I.	Middle, to Ind. and Mich. II.	Southern. III.	No. Central. IV.	La. and Ark. V.	Tex., Kan., and Pacific. VI.
Miles operated	87,782	5,887	28,693	14,243	25,038	877	13,044
Trains per day—Passenger	2.16	3.85	3.30	1.47	1.40	1.35	1.12
" " " —Freight	3.91	3.56	5.96	2.81	3.12	6.61	2.10
Total	6.07	7.41	9.26	4.28	4.52	7.96	3.22
	cts.	cts.	cts.	cts.	cts.	cts.	cts.
Per train-mile—Earnings	148.8	147.4	146.0	108.9	153.2	82.4	230.0
" " —Expenses	90.3	101.0	90.4	71.5	88.0	60.8	121.0
Net earnings	58.5	46.4	55.6	37.4	65.2	21.6	109.0
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.
Per cent of expenses to earnings	60.8	68.5	62.0	65.4	57.2	77.1	52.4
Percentages on Detailed Expenses:							
Fuel for locomotives	9.31	12.42	9.28	6.64	8.80	5.30	10.68
Water supply	0.68	0.57	0.54	0.93	0.64	0.78	1.25
Oil and waste	1.06	1.02	1.26	0.91	0.95	0.51	0.61
Repairs of locomotives	6.19	5.86	6.75	5.77	5.73	1.42	5.69
Total engines	17.24	19.87	17.83	14.25	16.12	8.01	18.23
Repairs—Passenger cars	2.99	3.25	2.69	3.66	3.66	1.16	2.58
" —Freight cars	6.40	6.05	7.83	6.08	4.56	0.84	4.34
Passenger-car mileage	0.23	0.13	0.21	0.40	0.33	0.01	0.08
Freight-car mileage	2.21	1.18	3.66	0.48	0.82	0.01	0.64
Total cars	11.83	10.61	14.39	10.62	9.37	2.02	7.64
Engine service (wages)	7.72	6.98	7.71	7.23	8.68	3.66	7.45
Train service—Passenger	2.85	3.58	3.10	2.46	2.50	1.51	2.20
" " —Freight	5.64	4.55	6.91	4.13	4.77	1.90	3.83
Train supplies—Passenger	0.33	0.38	0.23	0.54	0.43	0.21	0.34
" " —Freight	0.36	0.31	0.28	0.56	0.41	0.23	0.48
Total train wages and supplies	16.90	15.80	18.23	14.92	16.79	7.51	14.30
Total train expenses	45.97	46.28	50.45	39.79	42.28	17.54	40.17

Repairs of road bed and track	11.23	10.51	10.13	12.12	12.45	13.59	13.63
Renewals—Rails	4.89	4.03	3.86	8.61	5.71	6.03	5.65
" —Ties	3.04	2.64	2.78	4.30	3.07	4.21	3.48
Repairs—Bridges	2.55	2.10	1.84	3.66	3.76	2.57	3 04
" —Buildings	2.17	3 95	2.24	2.00	1.64	0.76	1.60
" —Fences, crossings, etc.	0.42	0.59	0.36	0.14	0.68	0.12	0.31
Total maintenance of way	24.30	23.82	21.21	30.83	27.31	27.28	27.71
Total transportation expenses	**70.27**	**70.10**	**71.66**	**70.62**	**69.59**	**44.82**	**67.88**
Loss and damage—Freight	0.28	0.25	0.21	0.59	0.29	0.40	0.29
" " " —Property and cattle	0.31	0.18	0.14	0.75	0.52	0.32	0.49
" " " —Passengers	0.39	0.39	0.33	0.40	0.45	0.33	0.60
Total loss and damage	0.98	0.82	0.68	1.74	1.26	1.05	1.38
Agents and station service	10.42	12.20	11.19	9.00	10.02	4.15	7.95
Station supplies	0.81	1.20	0.58	0.62	1.40	0.70	0.63
Telegraph	1.01	0.54	1.13	0.84	1.08	0.28	0.98
Taxes	3.77	4.97	3.39	1.91	4.42	1.95	5.08
General officers and clerks	3.46	3.18	2.52	5.86	4.42	4.90	4.17
Legal	0.70	0.50	0.44	1.09	0.80	1.26	1.57
Insurance	0.26	0.40	0.23	0.29	0.28	0.10	0.31
Stationery and printing	0.76	0.78	0.70	0.90	0.83	0.60	0.80
Agencies and advertising	1.34	0.73	1.50	1.35	1.46	0.53	0.97
Contingent and miscellaneous	6.22	4.58	5.98	5.78	4.44	39 66	8.28
Total station and general	**29.73**	**29.90**	**28.34**	**29.38**	**30.41**	**55.18**	**32.12**
Grand Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total cost per train-mile in cents, as above	90.3	101.0	90.4	71.5	88.0	60.8	121.0

CENSUS GROUPS.—I. The six New England States. II. The four "Middle" States, with Maryland, Ohio, Indiana, and Michigan. III. The Southern States east of the Mississippi and south of the Potomac and Ohio rivers. IV. Illinois, Iowa, Wisconsin, Missouri, Minnesota. V. Louisiana, Arkansas, Indian Territory. VI. Dakota, Nebraska, Kansas, Texas, and the States and Territories west thereof.

The figures for Group V. include only 877 miles in Louisiana and Arkansas, and the details of expenses are practically worthless because one large company reported nearly every expense as "Contingent and Miscellaneous." The close correspondence of the remaining columns, under very different operating conditions, is very notable.

TABLE 76.

DETAILS OF EXPENSES AND TRAFFIC FOR EIGHT TRUNK LINES.

[Computed from the Statistics of the Census of 1880. Averages for this Table, and for the preceding and following Tables, are shown in Table 78.]

	FOUR LEADING TRUNK LINES.				FOUR MINOR TRUNK LINES.			
	Pennsylvania.	Balt. & Ohio.	N. Y. C. & Huds. R.	N. Y., L. Erie & W.	Boston & Albany.	N. Y., Pa. & Ohio.	Pittsb'g, Ft. Wayne & Ch.	Louisv. & Nashv.
Miles operated	1,806	1,528	993	1,009	324	512	468	1,251
Trains per day (av. of entire miles operated). Passenger	5.1	3.1	7.0	4.5	5.9	1.4	4.5	1.8
Trains per day (av. of entire miles operated). Freight	10.3	8.3	16.0	11.1	14.4	4.5	14.0	3.0
Total	15.4	11.4	23.0	15.6	20.3	5.9	18.5	4.8
	cts.	cts.	cts.	cts.	cts.	cts.	cts.	cts.
Per train-mile—Earnings	187	143½	176	163	149	105½	144	184
" " " —Expenses	109	82	107	108	109	79½	73	98
Net earnings	78	61½	69	55	40	26	71	86
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.
Per cent of expenses	58.4	57.0	60.9	66.6	73.2	75.3	51.1	53.2
Percentages on Detailed Expenses:								
Fuel for locomotives	7.16	6.18	12.92	9.12	11.72	8.62	6.66	8.47
Water supply	0.33	0.70	0.11	0.53	0.60	0.45	0.45	0.79
Oil and waste	1.21	2.43	1.59	1.25	1.04	1.08	1.25	0.40
Repairs of locomotives	9.60	11.57	5.42	4.70	7.02	8.70	6.77	5.41
Total engines	18.30	20.88	20.04	15.60	20.38	18.85	15.13	15.07
Repairs—Passenger cars	3.55	3.38	3.43	1.77	2.61	2.76	3.14	2.68
" —Freight cars	6.42	21.70	9.98	5.61	9.13	8.22	9.20	8.06
Mileage—Passenger cars	0.30	......	......	0.67	......	......	0.07	0.41
" —Freight cars	5.78	......	9.27	0.40	0.05	7.44	0.17	.....
Total cars	16.05	25.08	22.68	8.45	11.79	18.42	12.58	11.15

Engine service (wages)	6.82	7.60	6.92	7.92	7.12	6.90	11.44	9.03
Train service—Passenger	2.07	1.43	1.35	2.46	2.29	1.89	3.37	1.79
" " —Freight	7.18	5.38	3.07	7.09	5.70	7.57	8.59	5.26
Train supplies—Passenger	0.44	......	......	0.09	0.08	0.22	0.32	.18
" " —Freight	0.43	......	......	0.05	0.03	1.02	0.32	1.61
Total train wages and supplies	16.94	14.41	11.34	17.61	15.22	17.60	24.04	18.87
Total train expenses	51.29	60.37	54.06	41.66	47.39	54.87	51.75	45.09
Repairs road bed and track	10.72	6.48	6.32	7.27	9.26	10.16	13.36	6.25
Renewals—Rails	1.15	6.77	2.33	1.85	2.07	5.72	1.12	7.06
" —Ties	2.60	2.51	2.03	2.28	2.86	2.32	2.86	5.61
Repairs—Bridges	1.45	1.12	0.06	2.03	1.00	1.48	1.89	2.97
" —Buildings	3.35	1.72	1.58	1.86	5.55	1.83	2.32	2.33
" —Fences, crossings, etc	0.10	......	0.30	0.33	0.39	0.45	1.03	0.11
Total maintenance of way	19.37	18.60	12.62	15.62	21.13	21.96	22.58	24.33
Total transportation expenses	**70.66**	**78.97**	**66.68**	**57.28**	**68.52**	**76.83**	**74.33**	**69.42**
Loss and damage—Freight	0.14	0.32	0.44	0.16	0.31	0.02	0.19	0.44
" " " —Property and cattle	0.14	0.32	0.03	0.02	0.04	0.01	0.07	1.46
" " " —Passengers	0.09	......	0.43	0.20	0.49	0.07	0.29	1.32
Total loss and damage	0.37	0.64	0.90	0.38	0.84	0.09	0.55	3.22
Agents and station service	10.59	8.27	19.40	20.64	12.48	6.54	10.16	10.43
Station supplies	0.83	......	......	0.32	0.97	1.08	0.52	1.38
Telegraph	1.93	1.19	......	0.96	0.37	1.98	1.62	1.54
Taxes	1.86	2.56	4.98	2.50	6.42	0.19	4.42	1.64
General officers and clerks	2.35	2.70	1.69	1.86	1.70	3.43	0.78	4.95
Legal	0.35	......	0.24	0.48	0.27	0.40	0.34	1.42
Insurance	0.46	......	0.09	0.49	0.40	......	......	0.05
Stationery and blanks	1.04	0.81	0.49	0.67	0.56	0.23	0.73	1.24
Agencies and advertising	1.11	1.54	2.80	3.36	0.16	1.41	3.71	1.57
Contingent and miscellaneous	8.45	3.32	2.73	11.06	7.31	7.82	2.84	3.14
Total station and general	**29.34**	**21.03**	**33.32**	**42.72**	**31.48**	**23.17**	**25.67**	**30.58**
Grand total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total cost per train-mile, in cents	109.0	82.0	107.0	108.0	109.0	79.5	73.0	98.0

TABLE 77.

DETAILS OF EXPENSES AND TRAFFIC OF THE SIX LEADING CHICAGO LINES.

[Computed from the Statistics of the Census of 1880. Averages for this table and the two preceding tables are given in the following table.]

	Chicago & Alton.	Ch., Burlington & Quincy.	Ch., Milwaukee & St. Paul.	Chicago & No. W.	Ch., Rock Isl. & P.	Ill. Central.	Six Chicago Lines.
Miles operated	841	1,882	3,000	1,691	1,297	1,306	......
Trains per day (av. of entire mileage)—Passenger	2.2	1.7	1.1	2.2	1.9	1.6	1.8
" " " " —Freight	4.6	4.8	1.9	5.4	5.6	2.9	4.2
Total	6.8	6.5	3.0	7.6	7.5	4.5	6.0
	cts.	cts.	cts.	cts.	cts.	cts.	cts.
Per train-mile—Earnings	168	181	166	168	150	159	165.3
" " " —Expenses	92	90	97	74½	81½	89	87.3
Net earnings	76	91	69	93½	68½	70	78.0
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.
Per cent of expenses	54.8	49.8	58.3	44.3	54.3	55.9	52.9
Percentages on Detailed Expenses:							
Fuel for locomotives	9.26	9.07	11.24	9.59	10.01	6.07	9.21
Water supply	0.39	0.96	......	......	......	0.96	0.38
Oil and waste	0.39	1.29	1.13	1.02	1.29	0.40	0.92
Repairs of locomotives	7.47	6.92	5.07	5.91	5.26	4.35	5.83
Total engines	17.51	18.24	17.44	16.52	16.56	11.78	16.34
Repairs—Passenger cars	2.32	10.98	2.58	2.32	8.97	2.33	8.55
" —Freight cars	5.83		6.27	5.21		4.48	
Mileage—Passenger cars	......	......	......	0.21	......	0.48	0.11
" —Freight cars	......	......	0.15	0.25	2.51	1.47	0.73
Total cars	8.15	10.98	9.00	7.99	11.48	8.76	9.39

Engine service (wages)	10.95	11.02	9.34	10.35	9.64	7.64	9.82
Train service—Passenger	1.70	2.49	2.52	3.42	1.89	2.63	2.44
" " —Freight	4.98	4.97	4.19	3.40	3.46	3.72	4.12
Train supplies—Passenger	0.13	0.55	0.55	0.26	0.45	0.54	0.42
" " —Freight	0.13	0.55	0.71	0.26	0.51	0.69	0.47
Total train wages and supplies	17.89	19.58	17.31	17.69	15.95	15.22	17.27
Total train expenses	43.55	48.80	43.75	42.20	43.99	35.76	43.01
Repairs road-bed and track	11.92	11.18	11.60	7.79	15.02	19.65	12.19
Renewals—Rails	4.10		9.00	5.40	5.00	3.28	4.46
" —Ties	2.27	6.43		3.94	......	2.45	3.18
Repairs—Bridges	3.45	4.97	2.19	3.66	4.05	1.92	3.37
" —Buildings	3.11	1.21	1.87	2.17	2.62	0.93	1.99
" —Fences, crossings, etc	0.96	0.70	0.65	1.13	0.56	0.88	0.82
Total maintenance of way	25.81	24.49	25.31	24.09	27.25	29.11	26.01
Total transportation expenses	**69.36**	**73.29**	**69.06**	**66.29**	**71.24**	**64.87**	**69.02**
Loss and damage—Freight	0.59	0.09	0.09	0.31	0.21	0.14	0.24
" " " —Property and cattle	0.59	0.75	0.19	0.10	0.46	0.18	0.29
" " " —Passengers	1.17		0.60	0.76	0.60	0.28	0.66
Total loss and damage	2.35	0.84	0.88	1.17	1.27	0.60	1.18
Agents and station service	12.20	8.71	14.54	18.12	13.44	10.14	12.86
Station supplies	3.99	1.36	1.11	1.65	1.39	2.46	1.99
Telegraph	0.21	2.01	......	......	0.16	1.57	0.66
Taxes	4.32	4.11	5.25	4.77	5.07	10.37	5.65
General officers and clerks	2.86	5.34	2.93	3.10	1.91	4.04	3.36
Legal	0.97	0.59	0.74	......	0.59	0.94	0.64
Insurance	0.13	0.58	0.30	......	0.03	0.56	0.27
Stationery and blanks	1.06	0.60	0.53	0.74	1.01	0.93	0.81
Agencies and advertising	0.69	2.22	1.40	1.48	......	1.00	1.13
Contingent and miscellaneous	1.86	0.35	3.26	2.68	3.89	2.52	2.42
Total station and general	**30.64**	**26.71**	**30.94**	**33.71**	**28.76**	**35.13**	**30.98**
Grand total	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total cost per train-mile, in cents	92.0	90.0	97.0	74.5	81.5	89.0	87.3

TABLE 78.

SUMMARY OF EXPENSES AND TRAFFIC OF ALL AMERICAN RAILWAYS AND OF VARIOUS GROUPS OF LINES, REPEATED FROM THE THREE PRECEDING TABLES, AND FROM THE FORMER EDITION OF THIS TREATISE.

	Four Trunk Lines.	Four Minor Lines.	Six Chicago Lines.	Average U. S.	Average 13 Roads, 1865–75.	Average N. Y., Mass., and Ohio Reports, 1869–73.	Assumed Averages. In Former Edition.	Assumed Averages. In This Edition.
Miles operated	......	.....	......	87,782	......	......	......	......
Trains per day (av. of entire mileage) — Passenger	5.1	3.2	1.8	2.16	......	......	......	......
Trains per day (av. of entire mileage) — Freight	12.5	8.0	4.2	3.91	... ..	......	......	......
Total	17.6	11.2	6.0	6.07	......	......	......	......
	cts.	cts.	cts.	cts.	cts.	cts.	cts.	cts.
Per train-mile—Earnings	157.9	155.1	165.3	148.8	......	......	......	......
" " " —Expenses	101.5	89.9	87.3	90.3	105.0	105.0	100.	100.
Net earnings	56.4	65.2	78.0	58.5	......	......	......	......
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.
Per cent of expenses	64.4	63.2	52.9	60.8	......	......	......	......
Percentages on Detailed Expenses:								
Fuel for locomotives	8.84	8.87	9.21	9.31	10.4	10.9	10.	9.5
Water supply	.42	.57	.38	.68	2.5 (water supply and oil and waste together)			.5 (water supply and oil and waste together)
Oil and waste	1.62	.94	.92	1.06		1.4	2.	1.0
Repairs of locomotives	7.82	6.98	5.83	6.19	9.7	7.5	9.	7.0
Total engines	18.70	17.36	16.34	17.24	22.6	19.8	21.	18.0
Repairs—Passenger cars	3.04	2.80	8.55 (passenger and freight cars together)	2.99	......	......	......	3.
" —Freight cars	10.93	8.65		6.40	......	......	......	7.
Mileage—Passenger cars	.24	.12	.11	.23	......	......	......	......
" —Freight cars	3.86	1.92	.73	2.21	......	......	......	2.
Total cars	18.07	13.49	9.39	11.83	10.6	10.0	10.	12.

Engine service (wages)	7.32	8.62	9.82	7.72	6.6	6.2	6.	8.
Train service—Passenger	1.83	2.34	2.44	2.85	6.3			
" " —Freight	5.68	7.78	4.12	5.64		6.1	6.	8.5
Train supplies—Passenger	.13	.45	.42	.33	......	......	......	.5
" " —Freight	.12	.74	.47	.36	......	......	......	
Total train-wages and supplies	15.08	18.93	17.27	16.90	12.9	12.3	12.	17.
Total train expenses	51.85	49.78	43.01	45.97	46.1	42.1	43.	47.
Repairs road bed and track	7.70	9.76	12.19	11.23	.....	......	......	12.
Renewals—Rails	3.02	3.99	4.46	4.89	......	......	.....	2.5
" —Ties	2.36	3.41	3.18	3.04	......	......	......	3.
Repairs—Bridges	1.16	1.83	3.37	2.55	......	......	......	
" —Buildings	2.13	3.01	1.99	2.17	......	......	......	5.5
" —Fences, crossings, etc.	.18	.50	.82	.42	......	......	......	
Total maintenance of way	16.55	22.50	26.01	24.30	27.3	26.7	27.	23.
Total transportation expenses	**68.40**	**72.28**	**69.02**	**70.27**	**73.4**	**68.8**	**70.**	**70.**
Loss and damage—Freight	.26	.24	.24	.28	......	......	......	......
" " " —Property and cattle	.13	.39	.29	.31	......	......	......	......
" " " —Passengers	.18	.54	.66	.39	......	......	......	......
Total loss and damage	.57	1.17	1.18	.98	......	......	......	1.
Agents and station service	14.72	9.90	12.86	10.42	......	......	......	11.
Station supplies	.29	.99	1.99	.81	......	......	......	
Telegraph	1.02	1.38	.66	1.01	......	......	......	1.
Taxes	2.98	3.17	5.65	3.77	......	......	......	4.
General officers and clerks	2.15	2.71	3.36	3.46	......	......	......	
Legal	.27	.61	.64	.70	......	......	......	4.
Insurance	.26	.11	.27	.26	......	......	......	
Stationery and blanks	.75	.69	.81	.76	......	......	......	1.
Agencies and advertising	2.20	1.71	1.13	1.34	......	......	......	2.
Contingent and miscellaneous	6.39	5.28	2.42	6.22	......	......	......	6.
Total station and general	**31.60**	**27.72**	**30.98**	**29.73**	**26.6**	**31.2**	**30.**	**30.**
Grand total	100.00	100 00	100.00	100.00	100.00	100.00	100.00	100.00
Total cost per train-mile, in cents	101.5	89.9	87.3	90.3	105.0	105 0	100.0	100.0

6 (112, 113, 114, 116, and two of 118 miles) under 120 miles.
4 (120, 121, 125, and 126 miles) between 120 and 130 miles.
6 (130, 131, 133, 133, 134, 134 miles) between 130 and 140 miles.
1 (145 miles) between 140 and 150 miles.
2 (150, 152 miles) over 150 miles.

Thus the minimum is 112 and the maximum 152 miles. This practice tends strongly to economy.

156. General and Station Expenses are but slightly affected by any probable variations in the line and grades, so that it is unnecessary to consider them in detail, although, for many questions connected with the operations of railways, such analysis is highly important. They amount altogether to about thirty per cent of the total operating expenses, ranging from twenty to forty per cent in extreme cases.

157. In Tables 75, 76, 77, 78 are given various details as to expenditures for the railways of the entire United States and the several interior groups thereof, for the four great trunk lines, for four minor trunk lines, and for the six leading Chicago lines. These details are all computed from the census statistics of 1880, which were the first which gave an available source for obtaining these statistics, on an approximately sim-

Table **79.**

Operating Expenses of British Railways, 1884–85.

	Cents per Train-mile.	Per Cent.
Maintenance of way	11.32	18.1
Locomotive power	16.55	26.4
Rolling stock	6.05	9.7
Traffic expenses	19.77	31.6
General charges	2.87	4.6
Rates and taxes	3.45	5.5
Government duty	0.68	1.1
Compensation:		
Personal injuries	0.27	0.4
Damage to goods	0.34	0.5
Legal and parliamentary expenses	0.51	0.8
Miscellaneous	0.79	1.3
Totals	62.60	100.0

No material change in the percentages of these various expenses has taken place since 1870, but the cost per train-mile has fallen from an average of 77 cents to 62.6.

ilar basis of distribution of expenses. Many minor errors plainly occurred in making over the accounts according to the census form; but the result is more likely to afford a uniform basis of comparison than any individual attempts to do the same thing with later statistics.

In Table 78 are likewise repeated the final results of a large table, which the writer computed for his former edition, from the accounts of seventeen different roads, each averaged for from three to ten years. It will be seen that the correspondence between these various statistics is singularly close—quite enough so to afford a pretty accurate basis for estimating the expenses of any road. In Table 79 are given some corresponding statistics for English railways.

158. Summarizing the ground gone over, we may estimate the operating expenses of a railway in the North Central States, laid throughout with steel, and of good average character, about as in Table 80, on the previous page. With less accuracy this table will apply to railways in any part of the United States, the principal cause of variation being volume of traffic.

This estimate, however, is merely an average, as should always be remembered; to be corrected in each individual case according to local circumstances. It has been endeavored in this chapter to furnish a guide for such corrections, as far as possible, but nothing will fully take the place of intelligent examination

TABLE 81.

CLASSIFICATION OF OPERATING EXPENSES ADOPTED IN THE FORMER EDITION OF THIS TREATISE.

TRAIN EXPENSES. 43 p. c.	Engines ....21 p. c.	Fuel..........10	p. c.
		Oil, waste, etc.......... 2	"
		Repairs.......... 9	"
	Cars.......... 10 "	Repairs, inspection, etc......10	"
	Train wages........12 "	Engineman and firemen...... 6	"
		Conductor and brakemen.... 6	"
MAINTENANCE OF WAY. 27 p. c.	Track..........13 "	Renewal of rails.......... 7	"
		Adjusting track, etc.......... 6	"
	Road-bed........ 7 "	Renewal of ties.......... 3	"
		Earthwork, ballast, etc....... 4	"
	Yards and structures 7 "	Switches, frogs, and sidings.. 3	"
		Bridges and bridge masonry. 2.5	"
		Station and other buildings... 1.5	"
TOTAL "LINE" OR TRANSPORTATION EXPENSES..........		70	p. c.
Station, Terminal, and General Expenses and Taxes..........		30	"
TOTAL OPERATING EXPENSES..........		100	p. c.

of the facts on neighboring roads. This table gives merely a rude average for use in the remainder of this volume for computing examples.

TABLE 82.

PERCENTAGE OF TOTAL REVENUE-MILEAGE (ASSUMED AS 100.) OF REVENUE-PASSENGER TRAINS, REVENUE FREIGHT TRAINS, "SWITCHING TRAINS," AND "OTHER" (MOSTLY WORK) TRAINS IN THE UNITED STATES AND EACH GROUP OF STATES.

[Computed from the Statistics of the Census of 1880. For Census Groups see Table 75.]

GROUP OF STATES.	Miles Operated.	Revenue Train-Mileage.			Other Mileage. (Per Cent of Rev. Miles.)		
		Passenger.	Freig't.	Total.	Switching.	Other.	Total.
New England	5,887	51.8	48.2	100.0	12.6	3.5	16.1
Middle, Ind., and Mich.	28,693	35.6	64.4	100.0	16.5	4.5	21.0
Southern	14,243	34.3	65.7	100.0	7.2	5.6	12.8
Ill., Ia., Wis., Mo., Minn.	25,038	31.2	68.8	100.0	16.1	5.9	22.0
La., Ark., Ind. T.	877	16.9	83.1	100.0	4.4	1.9	6.3
Far West and Pacific	13,044	34.8	65.2	100.0	10.8	9.0	19.8
United States	87,782	35.5	64.5	100.0	14.4	5.1	19.5

It is quite certain from the statistics that the actual proportion of switching mileage is larger than the above, both because fully one third of the roads do not report switching at all, and because many include switching with train-mileage. The per cent of switching to revenue-mileage of a few single roads runs as follows:

EASTERN.	Per Cent.	MIDDLE.	Per Cent.
Boston & Albany	12.9	Allegheny Valley	35.5
Boston & Lowell	18.	Atl. & Gt. Western	21.8
Cent. Vermont	13.8	*Balt. & Ohio*	5.6
Eastern	29.	Cl., Col., C. & Indianapolis	25.7
Fitchburg	21.	Cl. & Pittsburg	33.7
Maine Central	31.4	Col., Ch. & Ind. Central	21.1
Nashua & Lowell	32.4	*Del., Lack. & Western*	4.0
Old Colony	14.8	N. Y., L. Erie & W.	24.7
Prov. & Worcester	37.3	N. Y. Central & H. R.	33.5

The two roads given in italics above are among those which show an extraordinarily low cost per train-mile. The main cause therefor is clearly indicated in the above figures.

In Table 80 *one fifth* of the total cost of motive-power has been allotted to switching-engines. In most cases there is a larger proportion than this, independent of the switching done by regular trains *in transitu*, as is partly indicated by the following Table 82.

In Table 81 is given the table corresponding to Table 80, which was used in the former edition of this treatise as the assumed average distribution of expenses for computing examples.

PART II.

THE MINOR DETAILS OF ALIGNMENT.

"Despise not small things, for therefrom comes sorrow and disappointment. Yet remember that they are small, and fix your aims and your thoughts chiefly on the great ends of life."—HORACE MANN.

PART II.

THE MINOR DETAILS OF ALIGNMENT.

CHAPTER VI.

THE NATURE AND RELATIVE IMPORTANCE OF THE MINOR DETAILS OF ALIGNMENT.

159. THE three details of alignment which are properly to be classed as minor details are the following:

1. DISTANCE, or length of line.

2. CURVATURE, not sharp or so ill-placed as to limit the length or necessary speed of trains, but only to increase the expense of running trains.

3. RISE AND FALL, or elevations overcome by the engine on gradients not exceeding in resistance the maximum of the road, and hence not limiting the length of the train.

160. These are termed, collectively, the MINOR details, for the reason that their influence is comparatively trifling upon the future of the property in comparison with two other details of overwhelming importance, viz.:

1. THE AMOUNT OF TRAFFIC which the line has been or may be adapted to secure (often very largely and even ruinously affected by the location, for reasons discussed in Chapter III., the following Chapter VII., and Chapter XXI.), and

2. THE RULING GRADIENTS or other causes, whatever they may be, which limit the weight and length of trains, and so play the chief part in fixing the cost of handling the traffic. These causes are considered in Part III. of this volume, under the general head of "Limiting Gradients and Curvature."

To characterize three such details as distance, curvature, and rise and fall as minor details, either separately or collectively, does some violence to popular impressions, which exist even

among engineers. It will therefore be well that we should first see, by a "bird's-eye view" of the subject, free from all detail, why the designation is a proper one, nevertheless.

161. The ideal line for a railway between any two points is popularly felt to be a right line between the two termini. This may even be found stated as an axiom in some engineering works, and in a strictly engineering sense it is true. If it were true in every sense, it should follow that, in proportion as a line deviates therefrom, it is bad; and since the three details classified as "minor" include every possible deviation therefrom in either of the three dimensions of space,—curvature representing lateral deviations; rise and fall, vertical deviations; and distance, longitudinal deviations,—the three together, far from being MINOR details, seem naturally to represent or include all the conditions which make a line good or bad. This view is so far plausible, that it is asserted or implied to be the true one, not only in common talk, but in technical discussions or writings. "A short, straight line was obtained, with few curves or high elevations," will pass very generally as a description of what must be an excellent line.

Yet, as a matter of fact, this view is wholly erroneous—so gravely erroneous that the excellence or badness of the line in all the minor details put together, within wide limits, has comparatively a very slight influence on its value as an investment or on its usefulness to the public.

162. We shall see why this is true of each detail separately, as we come to consider each in detail. To see why it is true of all three put together, let us take the case of two railways between the same points—one a little shorter, a little less crooked, and with a little less up and down in its gradients; but suppose them both to have cost the same money, to have the same tributary population, to be able to haul the same trains with the same engines, and to make the same time between termini. These conditions obtain in many instances, and may conceivably in all. Nay, we might even extend our parallel, and assume that there are considerable differences in one or the other of the minor

details between the two lines, but always on the condition that they still remain minor details as already defined, in that they do not affect the sources of traffic nor the amount of traffic which can be handled by one train.

163. Which of these two lines is the best property? It is a matter of the merest chance—a mere question of management, or of business shrewdness in effecting connections. The difference in the minor details will beyond doubt be of large absolute importance, but will have so trivial an effect comparatively that it will hardly enter into the question at all.

164. This results simply from the broad general fact that those details affect only *the cost per trip of running trains, and that but slightly,* while they do not reduce, nor in any manner affect (within wide limits), either the work done or the revenue earned by each train. It is now abundantly established by experience that the effect of those details on the direct cost per trip or per mile of running trains is an exceedingly small percentage of the aggregate, within the widest limits of deviation which exist in practice. As for distance: the additional cost of running a few more miles is but a small portion of the average cost, and is always counterbalanced by the receipts of some additional revenue—often enough to make the advantage greater than the disadvantage, and always enough to greatly reduce the disadvantage. As for curvature, and rise and fall: it is now established beyond all question that no considerable difference in the aggregate expenses per train-mile on different railways, or on different divisions of the same railway, can be detected, which is clearly due to differences in the amount of curvature, or rise and fall, even when very marked differences in those details exist. Tables 75 to 80, as well as Table 83, afford cumulative evidence of this fact, which has been commented on at intervals from the very beginning of railroad history. One of the earliest records of the fact is the following statement of the eminent English engineer Mr. Charles B. Vignoles, formerly President of the Institution of Civil Engineers, as quoted with approval in Dempsey's "Practical Railway Engineer" (p. 11).

165. "Mr. Vignoles stated in a paper before the British Association for the Advancement of Science that he had analyzed railway expenses of working, and the average expenses of a train-mile, as deduced from several years' experience and observation on various railways operating under different circumstances and with greatly different gradients. The result was that on passenger and light traffic lines the total cost of a train-

TABLE 83

AVERAGE COST PER TRAIN-MILE OF RUNNING ENGINES ON THE SEVERAL DIVISIONS (DIFFERING WIDELY IN THE AMOUNT OF CURVATURE AND RISE AND FALL) OF THE PENNSYLVANIA AND PHILADELPHIA & ERIE RAILROADS.

Averaged on the Pennsylvania Railroad for a period of four years (1859–66–70–73), and on the Philadelphia & Erie for three years (1866–70–73).

[Reproduced from first edition of this Treatise.]

PENNSYLVANIA RAILROAD.

PHILADELPHIA & ERIE RAILROAD.

Divisions.	Average of all Engines.			
	Repairs.	Fuel.	Stores	Total
Eastern . . .	10 64	9 91	1 19	21 74
Middle . . .	11 1	9 77	1 19	22 06
Western	10 49	9 92	1 15	21 56
Average . . .	10 74	9.87	1.18	21.79

On the Philadelphia & Erie the expenses of engines are not kept separate for the different classes. The difference in the cost of repairs from that on the Pennsylvania Railroad is due, as the writer learns, to the very different character and condition of engines.

mile averaged 3*s.* per mile—2*s.* 6*d.* being the least, and 3*s.* 4*d.* the greatest; and that this average seemed to hold good *irrespective of grades and curves* [in italics as quoted]. It was not found practicable to distinguish the additional expense, if any; but as three fourths of railway expenses were quite independent of these causes, such additions must be small."

166. The essential truth of this statement has been growing better and better established with time to the present day, and we shall readily find evidence that it even understates the facts when we come to consider the effect of these details in the separate items of railway expenditure. From this it does not follow that these details have no important effect on expenses. They do have an important effect, which increases by a large percentage certain single items of expenses, and is readily traced therein. But they always add only a trifling percentage to the aggregate expenses, even when very marked differences exist.

167. And, moreover, the important further fact must be remembered that, as respects any one line, there can be at most, as we began by assuming (par. 162), only a "little" difference in

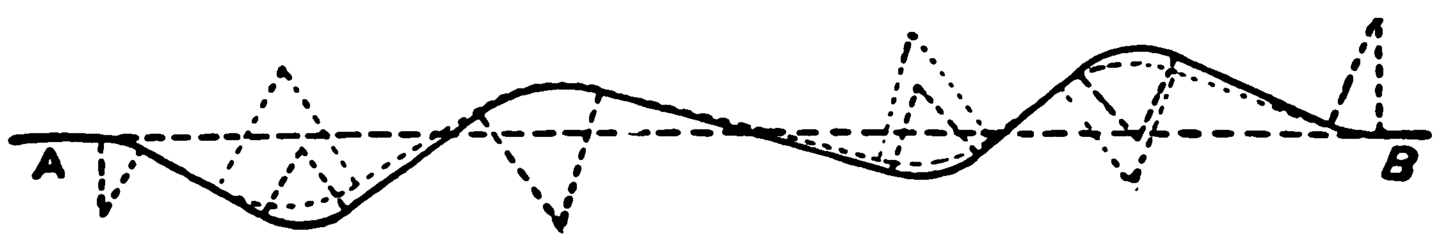

FIG. 5.

the minor details, for the vastest expenditure cannot effect much more. No possible expenditure can eliminate curvature altogether and give a continuous right line *AB*, Fig. 5, of any con-

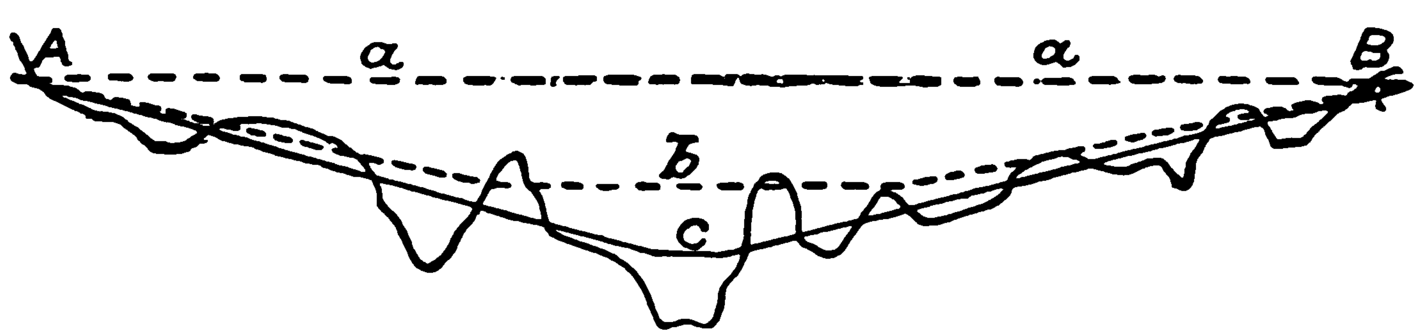

FIG. 6.

siderable length, in place of the curved line shown, nor make much more reduction in it than is indicated by the dotted line in Fig. 5; nor can we make more than a small difference in distance

ordinarily, nor have we more than the choice between the grade-lines *b* and *c*, Fig. 6 saving a mere fraction of the rise and fall. The grade-line *a*, taking out all the rise and fall between *A* and *B*, is rarely a financial or physical possibility.

168. For these reasons, assuming what cannot always be assumed, that the engineer has first done well in putting his line upon the ground so as to avoid unnecessary distance, curvature, and rise and fall (i.e., that which might have been eliminated without expense), to eliminate altogether even "little" differences in the minor details will ordinarily involve an immense expense. But grant them all to have been eliminated, without expense, from the least favored of the two lines which we began by assuming (par. 162), and let us see with somewhat more detail to what extent it will be benefited thereby. (For a more exact estimate see Chap. X.)

It will not reduce the interest charge, even if it do not (as it ordinarily must) increase it, and that takes, say, one third of the receipts. As respects the remaining two thirds of the receipts, which includes what are ordinarily termed "operating expenses:" It will not reduce the number of trains, for the length of trains is not affected by them. Consequently,

It will not reduce train wages and supplies, which are (Table 80) some 17 per cent of the expenses;

It will not reduce station-agent's wages, nor station labor, nor the salaries of the general officers and clerks, nor taxes, nor terminal expenses, and these constitute some 30 per cent of the expenses;

It will somewhat affect repairs of engines and cars, fuel, oil and water, and maintenance of way, aggregating some 53 per cent of the operating expenses; but

169. It will not affect that portion of the cost of fuel and engine and car repairs which is due to yard and station work, stopping and starting, wear of paint and rotting of wood, natural running wear over the rest of the possible line, injury to boilers from cooling off, care and maintenance of shops (except in an indirect and trivial way), etc., etc. These causes together include an immense proportion of the total of these items.

We have seen (par. 142) that something like 28 per cent of the locomotives of New York State are used for yard work only, besides which a large proportion of the wear and tear and waste of power of engines in regular service comes from yard work and stopping and starting. Precisely how much, we will not now consider; but it will be plain in a general way that only a minute percentage of even the cost of engine and car repairs can be saved by improvements of line which do not reduce the number of trains required.

Then as to maintenance of way: All that degeneration which comes from the elements, from the decay of ties, from the growth of weeds; expenses for maintaining frogs, switches, sidings, yards, stations, bridges, culverts, crossings, signals, track-walkers (for the most part), track-watchmen, hand-cars, fences, etc., are virtually unaffected, or nearly so, by any modifications of line (except distance) which are within the power of the engineer to effect, as is likewise that portion of the wear of rails, ties, and surfacing which would exist on the best possible line, and which is on any long line (for none are everywhere unfavorable) by far the larger part of it.

170. There remains, therefore, only a very small fraction of about half the operating expenses, or a very small fraction of one third of the revenue, which varies directly with the minor details of alignment, whereas a full half (in round figures) of the operating expenses or a full third of the revenue varies directly with the number of trains. The smaller loss is still enough to justify and require the utmost care of the engineer to avoid it, but it is not enough to make it, ordinarily, anything but the worst of bad judgment to sacrifice the securing of good limiting gradients, or the reaching of more traffic points, to get "a short, straight, and level line," which may or may not mean a good line, for we shall see (Part III.) that, although a tolerably "level" line passing over low summits ordinarily means one with low ruling grades, yet that the two have no very exact relation to each other.

171. We may further enforce the very important moral of the

comparative unimportance of the minor details of alignment by what is really a close parallel from ordinary business life:

Let us assume the case of a large wholesale house which sends out its "drummers" to all parts of the country to obtain business. Every time it sends one out it has a reasonable certainty of selling something and a possibility of selling a good deal. Such a house may be compared to a railway corporation, which sends out its trains to secure a certain minimum but varying maximum of traffic.

Now in the conduct of such a business there are three ends:

1. To sell all the goods possible.
2. To dispense with all the miles of travel possible.
3. To reduce the cost of travel per mile.

So in planning a railway there are these three ends, precisely analogous to the former in their nature, and as nearly as may be in degree:

1. To sell all the transportation possible.
2. To dispense with all the train-miles possible.
3. To reduce the cost of running trains per mile.

172. Of all the three ends sought in the drumming business, the least important—the MINOR DETAIL of the drumming business—is to reduce the direct cost of travelling; the expenditures for railway and sleeping-car fares and to hotels. Not that they are unimportant, for the firm which was reckless about them might readily be ruined; but they are a MINOR DETAIL, of small effect upon the ultimate result, whether they be large or small, if the business as a whole be well planned and well conducted; and the firm which should concentrate its attention upon them, giving its thought to selecting routes where the travelling expenses per day or per mile were small, to the neglect of the more important question of securing more business or reducing the amount of travel required, whether its cost per mile or per day were large or small, would be justly deemed on the road to ruin.

No doubt many have been so ruined, for the petty end which

the dullest mind cannot fail to perceive and comprehend may fill, from that fact, an unduly large arc in the mental horizon of many.

173. And so not only some but many railways may be, as they have been, ruined as productive properties by the undue importance given by engineers to the minor details of alignment: those details which do not add at all to the traffic of the line, and which do not reduce at all the number of trains needed to handle it, but which simply effect a "picayune" saving in the cost per mile run; a saving which is often so slight as to be imperceptible, which still more often adds to the interest charge more than it saves, and not infrequently, as we shall see, results in a negative saving, or absolute loss from the larger expenditure.

As a matter of fact, the first and most important end in the conduct of the drumming business is *to get all the business possible:* everything else—both the drummer's time and his expenditures—is subordinate to that, because if the end is not secured the means must necessarily be bad. So with a railway corporation: the first and most important end, when there is any great difference between routes, is to put the line where there will most business come to it.

174. And, finally, the second most important end in the drumming business is to obtain the most business with the least possible aggregate of travel, because avoidable travelling is expensive, not only from its direct cost, but from its waste of the drummer's time and possible earnings in more productive localities. If in any possible way one drummer can be made to do the work of two, or two drummers the work of three, the economy is so great that any probable or possible difference in the drummer's expenses PER MILE will hardly affect the question at all. So with a railway corporation: the second most important end is to do their business with the least number of trains per mile, because making one train do what two did before saves all the expense of the extra train, whereas cutting out some curvature or distance will only save a part of it—and a very small

part. Until all has been done which can be done, therefore, to reduce the number of trains required, it is hardly worth while to give a thought to reducing the expenses per train-mile. Afterwards it becomes proper and important to reduce the latter also to the extent that is permissible without encroaching on the two more important ends; to get the business to carry and to make a few trains carry it.

175. The student can do no more profitable thing to qualify himself for the correct conduct of location than to ponder over the parallel thus drawn until it is clearly perceived to be essentially true, not only in substance but in degree; until he clearly perceives that the three ends of getting business, of saving needless travel, and of reducing the direct mileage expenditures should occupy about an equal proportion of the attention of an engineer building a railway and a drummer building up trade. Each is important. No one of them can be safely neglected; but each in the order given is far more important than the other.

Why this is so in railway business appears more in detail in the three following chapters.

CHAPTER VII.

DISTANCE.

176. THE effect of a variation in the length of a railway on the value of the property we have seen (Chap. III.) to be peculiar in this—that, alone among all the details of alignment, it has a direct and material effect, not only on expenses, but on the revenue or receipts, which tends very materially to reduce its financial disadvantage. As a contrary view, leading to a feeling that any longer distance between termini is an unmitigated misfortune, and a great one, is common even with engineers and practical railroad men, and as this view is as mistaken as it is common, and leads to much mistaken action, it will be well, before proving affirmatively that this view is an error, to point out the nature and source of the error (which is easily enough seen), since the presumption is strong that any view which is widely held is a true one.

177. Its origin lies in a series of plausible non sequiturs, which are, in a few words, these (no one of them being true):

1. Rates are (usually) fixed [illegible] per mile, *because* [illegible] the passenger [illegible] means ten per cent [illegible] (2) ten per cent [illegible]

2. But [illegible] as valuable [illegible] from [illegible] to the point [illegible] miles or [illegible] over a vast [illegible] (3) receive the same [illegible]

3. All extra distance adds greatly to the cost of the service (fallacy 1 and 2); adds nothing to the value of the service (true enough with certain limitations); hence adds nothing to revenue (fallacy 3), and hence is among the greatest of disadvantages: Q. E. D.

The truth is, not one single item of railway expenditure, large or small, not even fuel or wear of wheels, varies in direct ratio with distance, or in anything like direct ratio, and more than half of them are very slightly if at all affected thereby. On the other hand, a very large proportion—on some railways almost the whole—of the receipts does vary directly with the distance.

178. The reason why rates are so generally based more or less directly on distance hauled, and on nothing else except necessity, is not in the least that it is a primary factor in the cost of the service, but simply this: The sale of transportation, like the sale of any other commodity, is governed by the one universal business law of selling whatever is salable as dearly as possible (or at least as dearly as is prudent and wise), regardless of the cost of production. The selling price of no marketable commodity, whether transportation or houses or cotton cloth, is fixed by the cost of production, except that if it will not bring a profit on its cost it is no longer produced; and for railways any such attempt would be particularly senseless, for the reason that, as we have elsewhere seen (par. 40, 181), the cost of any particular sale of transportation may be considered as varying anywhere from zero upwards; depending, to a far greater extent than in any other commercial transaction, simply upon the amount that can be sold..

179. Thus it has happened that the distance transported has been made the basis for tariffs (when they have any basis whatever other than the amount which it is possible to collect), as measuring in a rude way, not the cost of the service, but the consumer's idea of its value. In point of fact, the distance transported is but one of many circumstances—and certainly not the most important—which fix the cost of transportation.

Grades, curvature, cost of construction, terminal expenses, volume of traffic, whether the cars return full or empty—all these have very much more to do with the cost of service than the mere distance transported, but they are entirely neglected in fixing schedules of rates, simply because the consumer is not conscious of receiving any value when he is transported over curvature or grades, but is conscious of receiving value when he is transported over distance. For this very humble reason only, and not because there is any natural equity in it, the railway taxes him for the one service and not for the other, so that it may even, to a certain extent and under certain circumstances, and so long as those circumstances continue, be a positive advantage to a line to have a few miles of extra distance, especially when additional way traffic is thereby secured.

180. The mere possibility of such effect makes it invariably necessary, in considering the effect of distance, to consider its effect on revenue as well as on expenses, even if the former be considered only to be disregarded. To disregard it is often the only proper course, for this reason if no other: As a question purely of public policy—that is to say, if the interests of the corporation were in all respects strictly identical with the interests of the community as a whole—the effect of distance upon operating expenses would be the only one which there would be need to consider, and its effect on revenue should not be considered at all. For since the real service rendered and paid for is the transportation of persons or property from one terminus to another, the precise length of track between the two should have no more effect upon the price paid than the precise amount of curvature or rise and fall, and much less than the rates of ruling grades. All should be considered or none should be. And even in the case of railways constructed by private enterprise for pecuniary profit, although the fact that, both by law and by fixed custom, there is a certain credit side to the disadvantages of a circuitous route and not to other disadvantages is entitled to a certain legitimate weight, yet the nature of this

credit side greatly affects the expediency of relying on it; for it is obtained, not by rendering more valuable service, nor by decreasing the cost of the service, but by the corporation availing itself of an arbitrary custom to transfer a portion of the burden arising from one element of an unfavorable line (and not of others) from its own shoulders to the public at large, or to its connecting companies.

Moreover, this is a variable power, which does not always exist at all. We will therefore, for the present, postpone all discussion of that side of the question, and neglect it wholly, until we have determined the effect of distance upon operating expenses.

181. As illustrating the vastly greater effect of other causes than distance on the cost of transportation:

Wm. von Nördling, one of the most eminent of Austrian engineers, in a study on the cost of railway transportation, *apropos* of a proposition for constructing large canals to connect the Danube with the Oder and the Elbe, submits some interesting calculations, in which he avoids the mistake so commonly made in such calculations (and oftener in Europe than elsewhere) of calculating the *average* cost per mile of transportation on the railroad, and assuming that to be the measure of the cost of transporting any greater or less amount of traffic any greater or less distance.

After calculating that the average cost per ton per mile on the Theiss Railway of Austria, in 1875, was 0.98 cent, exclusive of loading and unloading, he finds that additional freight under ordinary conditions would have cost 0.457 cent; with cars full one way and returning empty, 0.392 cent; and full both ways, 0.286 cent per ton per mile; while back load for cars that otherwise would return empty would have added only 0.180 cent per ton per mile to the expenses.

THE EFFECT OF DISTANCE ON OPERATING EXPENSES.

182. The cost of operating additional distance not only is not the same per mile as the average cost, but is not even a constant quantity per unit of additional length; that is to say, is by no means the same per mile when the addition to be considered is one mile as when it is twenty. With the small changes of distance which most frequently occur, the number of yearly trips of rolling-stock, the number of buildings and sidings, and

the considerable class of expenditures which vary therewith, remain practically constant, as well as (very frequently) train wages, and are not perceptibly affected until the change of length amounts to a considerable percentage. How much such RELATIVELY SMALL CHANGES OF LENGTH affect expenses we shall first consider.

183. MAINTENANCE OF WAY.—The entire cost of maintenance of way proper (excluding yards and structures) may, without any serious exaggeration, be considered as varying with changes of distance as great as 2 or 3 miles; but it is not true, even of such items as track labor and track watchmen, that they are appreciably affected by variations of a few hundred feet, or even, sometimes, of as much as half a mile in distance. This results from the fact that the cost of track labor is, and will be still more in the future, fixed by other causes than the precise amount of labor to be performed. It is essential for safety that there should be a gang of men, large enough to handle a hand-car and put in a rail, every 5 or 6 miles; and to this end, in practice, the road is divided up into an even number of sections of about that length, and a minimum number of men assigned to each, whose duty during a large portion of the year is simply watchfulness and "tinkering." It is only during a few months in the spring and summer that the amount of labor put upon the track varies strictly with the distance.

It is safer, however, to consider that all track and road-bed expenses (15 cts. or per cent—Table 80) will vary directly with distances large enough to be measured by miles or quarter-miles, as they will certainly do when the distances become as great as of 2 or 3 miles; but for distances of a few feet or stations there is no reasonable possibility that other items than rail wear, tie renewals, ballast, and fencing will increase in direct ratio.

184. FUEL.—A very considerable percentage of the consumption of fuel is a constant wastage independent of the exact distance run. The cost of kindling fires alone averages 8 or 10 per cent of the total, as shown in Table 84. A fire-box full of coal is wasted every time the fire is drawn, which was formerly about every 100 miles run, but is now, on an average of a whole road, nearer to every 1000 miles, owing to the introduction of the practice of banking fires, especially with the long-trip system. This practice saves no fuel, however, but rather wastes some, its advantage being wholly in saving of time and of injury to the loco

TABLE 84.

SHOWING THE RELATIVE COST OF WOOD FOR KINDLING ON THE PHILADELPHIA & READING RAILROAD FOR A SERIES OF YEARS.

YEAR.	PERCENTAGE OF THE COST OF KINDLING-WOOD TO REMAINING COST OF FUEL.			PRICES OF FUEL.		Average Consumption of Wood for Kindling.
	Passenger Trains.	Freight Trains.	Coal Trains.	Wood per Cord.	Coal per Ton.	
1867.....	14.2	10.	5.1	$5 79	$3 15	Passenger trains, .13 c'd.
1869.....	8.8	6.4	3.6	5 50	3 80	Freight " .15 "
1873.....	9.7	6.2	4.1	5 94	3 25	Coal " .22 "
Average.	10.9	7.5	4.3	$5 74	$3 40	

The above does not include the cost of any coal used in kindling. The consumption of wood seems very small; Mr. Trautwine ("Engineers' Pocket Book," p. 810) gives ⅛ cord as the average consumption.

When this road was using wood fuel entirely, passenger trains used 2.7 cords per 100 miles, or about 2⅛ cords per daily run of 93 miles. Allowing ¼ cord for getting up steam would amount to exactly 10 per cent.

MR. WILLIAM STROUDLEY, Loc. Supt. London, Brighton & South Coast Railway, in a paper before the Institution of Civil Engineers (1885) shows that the number of pounds of coal burned to raise 100 lbs. of steam from water at 70° F. was about 450 lbs., equivalent to from 3 to 4 lbs. of coal per train-mile when kindling fires once a week, or every 650 to 800 miles run. This amounts to almost exactly 10 per cent of the total quantity of coal burned per mile. He gives also tables showing that his passenger engines spend nearly half the time that they are nominally in service either in switching or standing still (mostly the latter), and only half the time running.

motive from expansion and contraction. This terminal wastage alone will average, therefore, some 400 or 500 pounds per 100 miles, sufficient to run a locomotive 5 to 10 miles, or 5 to 10 per cent of the total consumption. Whether the fires are drawn or not, a fire-box full of coal at least, and usually more, is wasted at the end of every trip.

185. The consumption due to stopping and starting and to standing idle in yards and on side tracks is also a heavy item, and may be considered as nearly independent of distance in the case of two nearly equal lines operated with the same number of stops and sidings between the same termini. The direct amount of loss of power in stopping a train running at 15 miles an hour is sufficient to lift it vertically nearly 8 feet, as will

be seen in Table 118, and at 30 miles an hour four times that height, or nearly 32 feet. The rolling resistance of a loaded freight or passenger train in motion on a level being, as will be seen hereafter, equivalent to that of a grade of less than 16 feet per mile, we have, from stopping and starting only, a waste of power sufficient to run the train one half mile in the one case and two miles in the other, causing a loss for an average number of stops for stations and crossings of something very close to 10 per cent of the total consumption. In such extreme cases as the Manhattan (elevated) Railway of New York, where there are stations about every three eighths of a mile, very nearly three quarters of the total consumption of fuel has been shown to be due to this cause. As to the wastage while standing idle, experiments made by Mr. Reuben Wells show that an engine with jacketing in perfect order, standing idle all day long in a yard, wholly protected from wind and using no steam in the cylinders, requires from 25 to 32 lbs. of coal per hour to keep up steam in the boiler, or nearly enough to run it a mile in service. For the short stops in actual service at least twice this amount per hour is probably wasted, including what is blown out of the safety valve, owing to all parts of the engine being hot, and a surprisingly great amount of time is spent on an average freight trip, and even passenger trips, in simply standing still. It will average over 4 hours per day, if not more, in freight service on single-track roads, not including the time lost at the beginning and end of the trip; and on the very fastest express runs experience has shown that fully one fourth of the time between termini is lost by stops. This amounts to a further waste of 3 to 6 per cent.

186. From all these causes together it is a very moderate estimate that about *one third* of the total cost of fuel is not affected by a slight change more or less in the length of the line. The average consumption of fuel per train-mile in both directions is not so greatly affected by grade that we need consider the question of whether the additional distance is on a grade or on a level. Going up grade the consumption is greatly increased, but there is no consumption of steam at all in going down grade, so that the average is only slightly increased.

187. REPAIRS OF ENGINES AND CARS.—It is exceedingly common, and for certain purposes proper enough, to assume these expenses to vary directly with distance, but for our present purpose this is very erroneous. The wear and tear of rolling-stock, it is plain, arises from several distinct causes, of which the regular running wear when in motion is only one. These causes are:

1. Deterioration from time and age: *Varying with time.*

2. Stopping and starting: *Varying with number of stops.*

3. Terminal service, getting up steam and drawing fires, switching, making up trains, etc.: *Varying with the number of trips,* independent of their length.

4. Effect of curvature and heavy grades: *Varying with the character of the alignment.* And, finally, we come to

5. Effect of regular running between stations on a tangent: *Varying with distance* (the additional effect of any curvature on a given distance being a separate matter).

ALL of these causes contribute to increase the cost of maintaining rolling-stock, and as the whole cannot be greater than the sum of all its parts, the effect of any one of them alone must be much less than the total cost unless the effect of the other four is insignificant. Each item will be seen to vary with a different cause and only with that, and only one of these causes is the exact length of track.

188. The mere statement of these facts at once makes probable that rolling-stock repairs cannot vary very directly with distance alone when the other causes of deterioration remain the same, although precisely how much each cause contributes to the total will probably always remain an indeterminate problem. Nothing but the most exhaustive experiments could settle it accurately. Hence we find that when men's attention is specially fixed upon the disadvantages of some one of these causes they are very apt, with entire good faith, to exaggerate the effect of that one cause, simply from momentary forgetfulness of how many other causes are also co-operating to make up the aggregate. If the effect of distance is under discussion, the whole cost of rolling-stock repairs will be charged off as so much per mile run, as if no other cause but mileage had any effect; but, on the other hand, if the disadvantages of some grade crossing are in question, we shall have the wear and tear resulting from that cause spoken of as something fabulous. And so about the injurious effect of some particularly crowded yard or objectionable curvature. But starting from the premise that the total effect of all these causes cannot be more than 100 per cent, we have in Table 85 a subdivision of this total, item by item, between the above five causes. As this has been done with great care to get the best attainable authority for each (which it would occupy too much space to give in detail), the margin for possible error is not great enough to be of moment, although no absolute exactness can be claimed for it.

TABLE 85.

DISTRIBUTION OF THE COST OF ENGINE REPAIRS TO ITS VARIOUS CONTRIBUTING CAUSES.

ITEM.	Total Cost of Item.	DISTRIBUTION. Effect of Time, Age, and Exposure.	Stopping and Starting at Way Stations.	Terminal: Getting Up Steam, Making Up Trains.	Curvature and Grades. (Approx. Average.)	Distance on Tangent between Stations.
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.
Boiler	20.0	....	2.	7.	4.	7.
Running gear	20.0	....	4.	2.	7.	7.
Machinery	30.0	1.	7.	3.	5.	14.
Mountings	.....	....	....	....	....	....
Lagging and painting	12.0	4.	....	2.	....	6.
Smoke box, etc	5.0	1.	....	1.	....	3.
Tender:						
Running gear	10.0	....	2.	1.	3.	4.
Body and tank	3.0	1.	....	1.	....	1.
Total	100.0	7.	15.	17.	19.	42.

TABLE 86.

DISTRIBUTION OF THE COST OF FREIGHT-CAR REPAIRS TO ITS VARIOUS CONTRIBUTING CAUSES.

ITEM.	Total Cost of Item.	DISTRIBUTION. Effect of Time and Age, independent of Work and Mileage.	Stopping and Starting.	Terminal: Making up Trains, etc.	Curvature and Grades.	Distance only between Stations on Straight Track.
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.
Wheels	30.	....	5.	2.	13.	10.
Axles, brasses, and boxes	30.	....	5.	2.	5.	18.
Springs	10.	....	2.	1.	1.	6.
Truck frame and fittings	5.	2.	1.	1.	....	1.
Brakes	5.	....	2.	1.	2.	....
Draw-bars	10.	....	4.	4.	2.	....
Sills and attachments	5.	1.	2.	2.	....	....
Car body, painting, etc.	5.	3.	0.5	0.5	....	1.
Total	100.	6.0	21.5	13.5	23.0	36.0

The proportionate cost of wheels, axles, and brasses above is perhaps large, and that of brakes and draw-bars small, but it is in accordance with the best attainable information.

189. In Table 85 each of the smaller items is as small as it can reasonably be made. Consequently not more than 42 per cent of the cost of the engine repairs appears to vary with the minor changes of length. The distribution to curvature and grades will be spoken of hereafter. It will, of course, vary greatly on different roads. Table 86 is a similar distribution of the cost of freight-car repairs based in part upon Tables 71 to 75, and in part on Table 87.

190. It will be seen that a considerably larger proportion of car repairs than of engine repairs is independent of distance, as is but natural. The cost of passenger-car repairs may be considered as not greatly different per train from that of freight trains, but the maintenance of the seats, furniture, and inside and outside ornamentation make up much more than half the cost of passenger-car repairs, so that the cost per train of all kinds of running wear is much less considerable.

TABLE 87.

ESTIMATED COST NEW, SCRAP VALUE, AND RATE OF DEPRECIATION OF FREIGHT CARS OF VARIOUS KINDS.

[Deduced from data published in the *National Car-Builder* of April, 1880.]

Box Cars.

	Labor.	Material.	Total.	Scrap Value.	Total Deprec'n.	Average Life. Years.	Annual Deprec'n.
Wheels......	....	....	$90.00	$35.00	$55.	4	$13.75
Axles........	....	....	45.00	15.00	30.	8	3.75
Brasses......	....	....	10.00	4.00	6.	3	2.00
Frame.......	....	....	94.94	25.00	70.	.35	2.00
Truck.......	$227.82	$12.12	239.94	79.00	161.	7.5	$21.50
Brakes.......	7.33	2.16	9.49	2.00	7.50	6	1.25
Draw-bars....	26.08	2.95	29.03	6.00	23.	6	3.83
Frame.......	52.85	6.79	59.64	10.00	50.	15	3.33
Roof.........	25.49	3.34	28.83	4.00	25.	8	3.12
Floor........	10.76	1.12	11.88	1.00	11.	10	1.10
Sides........	36.78	7.58	44.31	2.00	42.	20	2.10
Painting......	5.25	2.16	7.41	....	7.50	7	1.07
Trimmings...	13.29	6.23	19.52	3.00	16.	20	.80
Trusses......	5.89	1.13	6.02	3.00	3.	20	.15
Total, box c.	410.54	45.58	456.12	110.00	346.	9.1	$38.25
Stock cars....	388.72	42.68	431.40				

(over.)

TABLE 87.—*Continued.*

Flat and Coal Cars.

	Total Cost New.	Scrap Value.	Total Depreciat'n.	Average Life. Years.	Annual Depreciat'n.
Truck (as above)........	$239.94	$79.	$161.	....	$21.50
Brakes.............. ...	9.49	2.	7.50	6	1.25
Draw-bars..............	29.03	6.	23.	6	3.83
Frame...................	45.00	10.	35.	15	2.33
Floor....................	12.00	1.	11.	10	1.10
Sides	8.00	1.	7.	20	0.35
Fittings.................	5.00	1.	4.	20	0.20
Trusses..................	6.00	3.	3.	20	0.15
Painting.................	6.00	....	6.	7	0.88
Total.................	$360.46	$103.	$257.50		$31.59

PER CENT OF TOTAL DEPRECIATION.

	Flat Cars.	Box Cars.	Average.
Wheels...............	43.5	36.0	40.
Axles and brasses.....	18.2	15.0	16.6
Truck frame..........	6.3	5.2	5.7
Total truck.........	68.0	56.2	62.3
Brakes...............	4.0	3.3	3.6
Draw-bars.............	12.1	10.0	11.0
Frame................	7.4	8.7	8.0
Other parts...........	8.5	21.8	15.1
Total..............	100.0	100.0	100.0

With this table compare Table 73. The principal discrepancy between the two is that the cost of wheels is much less, and of brasses much more, in the latter. On the whole, this table is at least equally trustworthy.

The rule of the Master Car-Builders' Association is that 6 per cent per year, or say $30, shall be allowed for depreciation in value of freight cars, down to a minimum of 40 per cent of their original cost.

191. TRAIN WAGES.—The tendency, as already stated (par. 152), is more and more to fix all train wages directly by the mile, especially on the larger lines made up of several divisions and with heavy traffic, where the total number of trips a crew can run per month is, in fact, proportioned almost exactly to the length of the run. Some arbitrary

limit is fixed, varying from 2600 to 3500 miles, as a month's work. Dividing this by the length of each division gives the number of trips to constitute a month's work, the fraction being disregarded in favor of the employé. On a division 100 miles long 26 trips is a month's work; on a division 90 or 105 miles long 28.89 and 24.76 trips would be exactly a month's work, but the fraction would be dropped in favor of the employé, and 28 and 24 trips, respectively, called a month's work.*

192. Many of the smaller lines still pay no attention to the exact mileage run, and others (including probably over half the mileage of the United States) adopt the compromise plan already described (par. 154); but under any circumstances it will be seen that it is extremely unlikely that slight changes of length of a few hundred feet will affect train wages in any manner or under any circumstances whatever. The circumstances, and the probable standard of train wages, must be considered in each case, and in the summary below train wages are both included and excluded.

193. STATION AND GENERAL EXPENSES AND TAXES.—Taxes are nominally assumed at so much per mile, and no doubt really vary with mileage to some extent, in fact as well as in form. As they are in the long-run, however, based on value and not on cost, it can hardly be proper to consider them as varying with distance to any important extent, and unless a longer line between two given points increases the value of the property, they should not increase with distance at all. Station, terminal, and general expenses are of course entirely unaffected by any small changes of length, unless the volume of business or number of stations and side tracks is also increased.

194. Summing up the effect of distance on the various items of operating expenses, as in Table 88, we obtain as a final result, that fractional changes of distance increase or decrease expenses by only 25 to 40 per cent of the average cost of operating an equal distance, according as train wages are affected or unaffected. The limit of possible variation or error in this, as in all other such estimates, is no doubt a considerable percentage, but this is unavoidable. Exactitude enough to make us certain of having avoided grave error and hopeful of having avoided all error, is the utmost that is possible.

* Passenger trainmen often make much more than this, frequently running 6000 or more miles as a month's work.

TABLE 88.

ESTIMATED APPROXIMATE EFFECT ON OPERATING EXPENSES OF MINOR CHANGES OF DISTANCES, MEASURED BY FEET OR STATIONS, AND NOT BY MILES.

[Cost of train-mile assumed at $1.00.]

ITEM.	Total Cost by Table 80. Cts. or p. c.	Proportion of Same Increasing with Distance.	Cost of Running One Additional Train-Mile.
Fuel	7.6	67 per cent.	5.1
Water	0.4	unaffected.	....
Oil and waste	0.8	50 per cent.	0.4
Engine repairs	5.6	40 "	2.2
Switching-engines	5.2	unaffected.	....
Train wages	14.9	"	....
Train supplies	0.5	"	....
Car repairs	10.0	35 per cent.	3.5
Car mileage	2.0	100 "	2.0
Rail renewals	2.0	80 "	1.6
Adjusting track	6.0	50 "	3.0
Tie renewals	3.0	100 "	3.0
Earthwork and ballast	4.0	100 "	4.0
Yards and structures	8.0	unaffected.	....
Station, terminal, general, and taxes	30.0	"	....
Total	100.0	24.8 per cent.	24.8
train wages vary exactly with distance			39.7

For more considerable changes of distance see Table 89.

In the first edition of this treatise the cost of small additions to distance was estimated as follows:

	Total Cost of Item at $1 Per Train-Mile.	Proportion of Same Increasing with Distance.	Cost of Runn'g One Additional Mile.
Fuel	10 cts.	70 per ct.	7 cts.
Oil, waste, and water	2 "	50 "	1 "
Repairs of engines and cars	19 "	70 "	14 "
Train wages	12 "	unaffected by small changes.	....
Maintenance of way	27 "	all but yards and structures.	20 cts.
Station and general expenses	30 "	unaffected.	....
Total	$1.00	42 per ct.	42 cts.

The difference between this and the above estimate is partly owing to changes in operating conditions and partly to more correct estimate of the actual effect of slight additions of distance. At the time the first edition of this work was published an estimate that the cost of operating additional distance was only about 42 per cent of the average cost was something of a novelty, yet it really was an over-estimate.

COMPARATIVE VALUE OF GREAT AND SMALL REDUCTIONS OF DISTANCE.

195. When the saving or loss of distance is more considerable than we have been considering, or at some point varying from 2 to 10 or 15 miles, according to the practice and conditions of the road, a considerably larger proportion of expenses will vary with distance. The train wages and number of track sections will almost certainly do so. The cost of stopping and starting, maintenance of yards and sidings, and track labor generally will also be increased. This increase will be in detail about as computed in Table 89.

TABLE 89.

ESTIMATED APPROXIMATE EFFECT OF GREAT AND SMALL DIFFERENCES OF DISTANCE.

The smaller percentage is as in Table 51, for small differences of distance, and the table gives the estimated increased effect on each item of a greater difference of distance.

[Cost of train-mile assumed at $1.00.]

ITEM.	Total Cost by Table 80. Cts. or p. c.	Increase for Greater Differences of Distance of Per Cent varying with Distance—	Total Am'nt Per Train-Mile for Greater Differences of Distance.
Fuel	7.6	from 67 p. c. to 85 p. c.	6.5
Water	0.4	" 0 " " 50 "	0.2
Oil and waste	0.8	" 50 " " 50 "	0.4
Engine repairs	5.6	" 40 " " 57 "	3.2
Switching-engines	5.2	" 0 " " 0 "	....
Train wages	14.9	" 0 " " 100 "	14.9
Train supplies	0.5	" 0 " " 40 "	0.2
Car repairs	10.0	" 35 " " 50 "	5.0
Car mileage	2.0	" 100 " " 100 "	2.0
Rail renewals	2.0	" 80 " " 100 "	2.0
Adjusting track	6.0	" 50 " " 100 "	6.0
Tie renewals	3.0	" 100 " " 100 "	3.0
Earthwork and ballast	4.0	" 100 " " 100 "	4 0
Yards and structures	8.0	" 0 " " 50 "	4.0
Station, terminal, general, and taxes	30.0	" 0 " " 0 "	....
Total	100.0	from 24.8 p.c. to 51.4 p. c.	51.4
If train wages are not affected, we have			36.5

196. From the aggregates at the foot of Tables 88 and 89, we find that the total cost per train-mile for great and small changes of length compare about as follows:

COST PER TRAIN-MILE.

	Minor Changes. (Measured in Feet.)	*Greater Changes.* (Measured in Miles.)
If train wages are affected, .	39.7 cts. or per cent.	51.4 cts. or per cent
If train wages are not affected,	24.8 cts. or per cent.	36.5 cts. or per cent.

Multiply these sums by 365×2, and dividing the product by 5280 in the first column only, we obtain the following:

YEARLY COST PER DAILY TRAIN (ROUND TRIP) OF GREAT AND SMALL CHANGES OF LENGTH.

	Minor Changes. Per Foot.	Per Mile.	*Greater Changes.* Per Mile.
Train wages affected, ...	5.49 cts.	$290	$375
Train wages not affected, . .	3.43 cts.	$181	266.50

These sums, divided by the assumed or actual rate per cent which must be paid for capital, .05, .06, .08, .10, etc., will give the *justifiable expenditure* to save one foot or one mile of distance, as respects its effect on expenses only. Thus at 10 per cent cost of capital we may spend $\frac{\$375}{.10} = \$3750$ per mile to save considerable additions to distance.

These exact figures are of course hypothetical, to illustrate the general law, and need to be made up anew for any particular case—at least to the extent of correcting the assumed cost per train-mile, which averages 80 to 90 cts. rather than $1.00.

197. FOR VERY LARGE AND CONSIDERABLE DIFFERENCES OF DISTANCE, amounting to 20 to 30 miles in 100, the value of saving distance may properly be still further increased, even up to the figures at which all saving of distance without distinction is sometimes estimated. The conditions are then very greatly modified. The number of yearly trips of rolling-stock is then affected, and their number must be correspondingly increased or diminished, whereas smaller changes have no such effect. Gen-

eral expenses even will then be perceptibly affected, and almost every item of expenditure except the cost of making up trains and getting up steam will be very largely increased by the extra distance. The total cost of all train and maintenance of way expenses amounts in our assumed average (Table 80) to 70 cents or per cent; but as all experience seems to indicate that even direct train expenses cannot be reduced in practice, and will not increase in direct ratio to distance, even if the difference of distance were as much as 50 per cent (although it may appear that they should in theory), it is probable that 80 or 90 per cent of the above-mentioned total of way and train expenses, or say 56 cents per train-mile, is the maximum effect of the most considerable changes of distance. Or to put the whole thing into even figures: the average cost of a train-mile being taken for even figures at $1.00 (it is now usually less)—

The minimum effect of extra distance, measured in feet, is per train-mile	25 per cent or $\frac{1}{4}$
The minimum effect of distance, measured in miles, not affecting train wages, is	36.5 " " or $\frac{3}{8}$
The maximum effect of the most considerable change of distance is	56 to 63 " " or $\frac{5}{8}$

198. Between the extremes above given, the true valuation may be almost anywhere under different circumstances. There are even certain conceivable cases, which have sometimes occurred in practice, where the assumed maximum is not adequate, as for instance, in comparing two routes for a transcontinental line differing by 100 to 800 miles. The number of operating divisions will then vary, and with it a very large proportion of the general and station expenses, so that the extra distance may cost (or may not) 90 or even 100 per cent of the average cost; but such extreme cases are too exceptional for discussion.

199. The effect per year upon operating expenses of any given distance having been thus determined, the capital sum for which this yearly cost represents the interest will plainly be the sum which (neglecting all effect on revenue) we are justified in expending to cut out that distance. Thus, if distance be found, as

above, to cost 3.43 cents per daily train per foot, during one year, a road running 10 trains per day each way, and paying 8 per cent for capital, can afford to spend, to save one foot of distance, $4.29 *less* the value of the counterbalancing considerations which we have yet to consider. To this we may add, if we please, $2.00 per foot, more or less as the case may be, as the cost of superstructure, right of way, and fencing; or we may include that sum with the other items of construction. This value having been determined, the difference in cost of construction to sub-grade then enters in, to determine whether or not the given improvement will cost more than it is worth.

200. Errors have been committed, resulting in a great exaggeration of the value of saving distance, by assuming that the whole average cost of constructing a mile of line complete is to be added to the operating advantage of saving a mile of line to determine its total value. But the value of distance, like the value of everything else, is independent of its cost. Whether the permanent works beneath the track be costly or cheap, the value of cutting out that part of the length of the road will be the same for the same road with the same traffic. We therefore first estimate the value of the saving, and then estimate both alternate lines to see whether or not the value exceeds the cost.

All the preceding has been on the supposition that distance, like other advantages of alignment, is a pure source of expense and has no effect upon receipts—an entirely false supposition. We proceed now to consider the other side of the question.

THE EFFECT OF DISTANCE ON RECEIPTS.

201. All railway traffic is in common parlance roughly divided into "through" and "local," but what is through and what is local is a matter of varying definition. The literal interpretation of the word "through" freight would be freight passing over the entire distance between termini, whether exchanged with other lines or not, and this definition is often followed in classifying. Another basis for subdividing traffic into through and local is that adopted in the Massachusetts Railroad Reports; viz., to call all traffic "local" which is confined to the home road, and simply passes from one station of the road to another, whether those stations are the termini or not; and all traffic

"through" which is (under this definition) not local, but passes over parts of two or more lines, although the total haul may be only a few miles between small non-competitive stations; whereas "local" traffic may be hauled the entire length of the road at competitive rates, and be for all practical purposes what is ordinarily understood as "through" business.

202. Neither basis of division, therefore, is a particularly happy one for accomplishing the end sought, and the reason why neither can be is easy to see. The difficulty is that each of them is an attempt to include under only two classifications *five* distinct classes of traffic, each one governed by different laws as respects rates and other business considerations. These classes are:

A. { 1. Non-competitive local.
     2. Non-competive exchange.

B. { 3. Competitive local.
     4. Competitive exchange.

C. { 5. Partially competitive (i.e., competitive only with the disadvantage of a local haul in addition).

More in detail, the nature of these sub-classifications are as follows:

A. NON-COMPETITIVE.

(The whole of it being what is ordinarily referred to by the term "local" traffic.)

1. *Local or home traffic proper*, having no choice of route and confined to one line.
2. *Exchange traffic*, or (by Massachusetts classification) "through" traffic, having no choice of route, but passing from one line to another.

B. COMPETITIVE.

(The whole of it being what is ordinarily referred to by the term "through traffic.")

3. *Local or home traffic*, confined to one line, but having a choice of another route (a class of traffic once small, but rapidly increasing with the multiplication of railways).
4. *Exchange or "through" traffic proper*, passing between the more important railway centres, and with a choice of two or more routes.

C. PARTIALLY COMPETITIVE. 5. *Traffic* (usually exchange or "through") ***between non-competitive local points and important railway centres*** having a choice of route only at disadvantage, by paying a local rate in addition to the "through." This class does not exist, practically, for passenger service.

203. Out of all these five classes there is only one—viz., Class B, 3; traffic confined to the home road and therefore purely local, but having a choice of route by some other line and therefore competitive—on which a longer haul has no effect whatever to increase receipts, but is a pure disadvantage. This class is also, on most roads, the smallest class of all, and on very many it is entirely non-existent. On others, however, as for instance on a new line between New York and Philadelphia, it would be the bulk of the traffic. It is rapidly increasing in importance, moreover, from the prevalent tendency to consolidate lines into great systems, and even when this consolidation is not formal and complete, there is often such community of interest from common ownership as to amount to very nearly the same thing.

Receipts from all the other classes are affected materially by the distance; but in different ways, which we proceed to consider:

204. A. NON-COMPETITIVE (Class 1 and 2). Traffic between non-competitive way points, whether these points are on the same or different roads.

There is no real need for making a distinction between these two classes in respect to rates, the "through" being made simply by the addition of the two local rates, and divided in the same proportion.

This class of traffic, which is what is popularly meant by "way" traffic, is an immense factor in the freight revenue of any

railway, varying ordinarily from 50 to 75 per cent of it; and rarely falling below 50 per cent, except on lines of heavy through traffic running through sparsely settled districts. The old Canada Southern (now Michigan Central) is a peculiar and very exceptional example of a line of the latter character, its local ton-mileage having averaged, before its consolidation, below 8 per cent of the total. Even in this extreme case, however, its revenue from local freight appears to have been from 25 to 30 per cent of the total. The Cleveland, Columbus, Cincinnati & Indianapolis Railway, which carries perhaps as small a proportion of non-competitive freight as any other line for which precise statistics are available, and which is certainly exceeded in that respect by very few, derives, as an average of 9 years (1873–81), 36 per cent of its tonnage, 23 per cent of its ton-mileage, and about 38 per cent of its freight receipts from "local freight," which in this case includes, practically, non-competitive of all classes. In its passenger traffic this line enjoys an even larger proportion of non-competitive traffic, being at much less disadvantage in that respect, and in fact representing as nearly as may be the average condition of the whole American railway system. This is the more fortunate as it is one of the very few lines which give statistics of the passenger or any other traffic in such form that it can be accurately separated into at least four of the five classes of traffic which actually exist, as above specified. The following Table 90 gives the percentage of each of these classes (omitting fractions and distributing a trifling sum for miscellaneous receipts) for the average for the 9 years 1873–1881. The table may be accepted as giving, in a rough way, about the general average of the whole American railway system for passenger service.

205. Table 91 gives some corresponding details for the freight traffic of the same road, which can hardly be accepted as so representative, and in Table 92 (as also in various other tables; —see Index) are given data as to average train loads. The variations in such matters are limited only by the number of roads, and are often very great.

There is a certain portion of even non-competitive traffic, it must always be remembered, on which rates are governed solely by what it will bear, without any reference to distance, and on many roads a very large proportion, as where there is much suburban traffic; yet in the main the rates are nominally fixed by the mile on all this traffic, and on a certain large proportion they are by law or fixed custom actually so fixed.

Before considering what weight should be given to these facts in estimating the value of distance (for which see par. 227) we will consider the conditions which exist with the three remaining classes of traffic.

206. COMPETITIVE TRAFFIC, *whether confined to one line or not;* (classes 3, 4, and 5, above). The total through rates on all competitive traffic are, in nearly all cases, arbitrarily fixed, with little regard to the mileage. For this reason it may appear, and may be too readily taken for granted by engineers not familiar

TABLE 90.

COMPARATIVE MAGNITUDE OF THE SEPARATE CLASSES OF THROUGH AND LOCAL COMPETITIVE AND NON-COMPETITIVE PASSENGER TRAFFIC ON THE CLEVELAND, COLUMBUS, CINCINNATI & INDIANAPOLIS RAILWAY.

Average of 9 years, 1873–1881.

[This table may be accepted, in a rude way, as not far from the general average of the whole American Railway System.]

CLASS OF TRAFFIC AS SUBDIVIDED ON PAGE 212.		Per Cent of No. of Passengers.	Per Cent of Pass. Mileage.	Per Cent Contributed to Revenue.
A. Non-Competitive	1. Local home road	74	[illegible]	[illegible]
	2. Local or exchange between local points on different roads	24	[illegible]	[illegible]
B. Competitive	3. Local traffic between competitive termini; only partially in this case	[illegible]		[illegible]
	4. Competitive through	[illegible]	[illegible]	[illegible]
C. Partially Competitive.	(Non-existent in pass. service			
		[illegible]	[illegible]	[illegible]

TABLE 91.

FLUCTUATIONS AND DISTRIBUTION OF THE DIFFERENT CLASSES OF FREIGHT TRAFFIC; CLEVELAND, COLUMBUS, CINCINNATI & INDIANAPOLIS RAILWAY.

Local Freight.

YEAR.	EAST-BOUND.			WEST-BOUND.			TOTAL.		
	Tons. 1 = 1,000.	Ton-Miles. 1 = 1,000,000.	Rev. 1 = $1,000.	Tons. 1 = 1,000.	Ton-Miles. 1 = 1,000,000.	Rev. 1 = $1,000.	Tons.	Ton-Miles.	Rev.
1873...	419	50.0	908.9	211	20.8	434.8	630	70.8	1344.
1875...	401	43.3	686.7	253	27.7	465.0	654	71.0	1152.
1880...	564	74.6	749.8	311	33.6	451.6	874	108.2	1201.
1885...	451	43.3	469.7	355	41.0	406.3	806	84.3	876.

Through Freight.

YEAR.	Tons.	Ton-Miles.	Rev.	Tons.	Ton-Miles.	Rev.	Tons.	Ton-Miles.	Rev.
1873...	870	166.5	1895.	181	37.1	496.8	1050	203.5	2392.
1875...	747	145.5	1093.	209	46.8	402.8	957	192.3	1495.
1880...	1189	232.0	1539.	378	80.3	588.0	1567	312.2	2127.
1885...	1140	226.9	997.	569	117.4	598.6	1708	344.4	1596.

The above indicates the nature and extent of the fluctuations which have occurred during the thirteen years covered by the table. The following are AVERAGES FOR THE TEN YEARS 1876–1885:

PERCENTAGES OF TOTAL TONS CARRIED.	Through.	Local.	Total.	PERCENTAGES OF TOTAL TON-MILES.	Through.	Local.	Total.
East-bound...	48.4	19.9	68.3	East-bound...	56.5	12.5	69.0
West-bound...	17.7	14.0	31.7	West-bound...	21.8	9.2	31.0
Total.......	66.1	33.9	100.0	Total.......	78.3	21.7	100.0

PERCENTAGES OF TOTAL REVENUE.	Through.	Local.	Total.	AVERAGE RECEIPTS PER TON-MILE.	Through.	Local.	Total.
East-bound...	44.5	20.3	64.8	East-bound.	.556 ct.	1.161 cts.	.674 ct.
West-bound...	20.0	15.2	35.2	West-bound	.656 "	1.210 "	.818 "
Total......	64.5	35.5	100.0	Total....	.591 ct.	1.182 cts.	.719 ct.

TABLE 92.

AVERAGE TRAIN-LOAD OF FREIGHT AND PASSENGERS IN THE UNITED STATES, GROUPS OF STATES, AND ON TRUNK LINES.

[Computed from the Census Statistics of 1880.]

	Passenger Traffic.		Freight Traffic.	
	Av. Train-Load. No.	Av. Haul. Miles.	Av. Train-Load. Tons.	Av. Haul. Miles.
I. New England	53.3	16.8	90.6	55.7
II. Middle, with Md., Mich., Ind.	44.2	17.4	163.	106.1
III. Southern	21.3	44.1	55.7	103.7
IV. Ill., Ia., Wisc., Mo., Minn.	37.1	41.9	122.5	153.3
V. La., Ark., Ind. T.	18.3	39.8	61.	34.6
VI. Tex., Kan., Dak., and Far W.	48.0	44.8	95.5	166.9
Total United States	41.5	21.	129.	111.
TRUNK LINES.				
Boston & Albany	72.	......	110.	......
New York Central	65.	......	218.	......
N. Y., L. Erie & W.	55.	......	211.	......
Pennsylvania	52.4	......	233.	......
Baltimore & Ohio	38.	......	185.5	.....
N. Y., Penna. & O.	41.	......	113.	......
N. Y., N. Haven & Hartf.	90.	......	113.	.....

with operating practices, that, for this class of traffic at least, any additional distance must be a pure disadvantage, increasing expense, but not affecting revenue. And this is literally true with respect to such competitive traffic as begins and ends on one line, or on one system of lines with interests wholly in common. But, in spite of the present tendency to consolidation, a very large proportion of such traffic on all lines, and practically the whole of it on the smaller lines, is through freight proper, which passes over parts of several lines. On all such traffic the total rate from shipping point to destination is indeed arbitrarily fixed, without regard to mileage, and often in fact in inverse ratio to it; but of the division of this total rate between the participating companies, which is what practically concerns us, this is by no means the case.

207. The division in all such cases is by a percentage which is regulated strictly *in accordance with* the relative distance hauled, although not necessarily in direct ratio to that distance; for there are frequently "Arbitraries" of various kinds, and granted for various reasons, as for terminal expenses, to be first deducted before the final division or percentage is distributed according to mileage.

208. So, too, it is not uncommon for some line to have some strategic advantage of another, so that it can exact from it certain special concessions, in excess of its exact mileage proportion, such as allowances for "constructive mileage," etc., etc.

The Erie Railway formerly had a great strategic advantage of this kind over the old Atlantic & Great Western Railway (New York, Pennsylvania & Ohio), the nature and effect of which we shall shortly see (par. 216).

209. Again, when shipments are for extremely long distances they are quite frequently subject not to one, but to the sum of two competitive rates, and the total is divided accordingly. All freight passing through Chicago is a remarkable example of this. It is not common to make rates past Chicago to points on either side otherwise than by adding the two Chicago rates (which latter is very common), except when, as to "Missouri River points," special circumstances make it absolutely unavoidable. The tendency to make Chicago a terminal point for competition and start afresh from there, is strong.

There are some apparent partial exceptions to this rule, but they are hardly real ones. Thus in 1886, after considerable controversy and irregularity, rates from New York to "Mississippi River points," including a large number of points north of St. Louis, were by agreement adjusted at the fixed rate of 116 for 100 to Chicago. This was then divided between the lines east and west of Chicago (there being half a dozen or more lines interested on each side), by assuming the distance for all lines to be 220 miles west of Chicago and 970 miles east, these being about the average of the actual distances, which of course varied with each road. The total rate was then divided in exact proportion (as nearly as might be) to these distances, viz., 18½ per cent west and 81½ per cent east of Chicago. Exactly these divisions would have been 18.487 and 81.513, so that the rate on 0.15 mile of haul west of Chicago was given away to the lines east to obtain a round-numbered percentage.

In this exceptional instance the general rule that through competitive rates are regardless of distance is extended likewise to a first division of those rates into two parts. What the arrangement really means, however, is that, although a common aggregate rate to the Mississippi River points was desirable in the interest of peace and good-will, yet the distance was so great and the conflicting interests so multifarious that it was more convenient to regard this rate as made up of two separate and distinct through rates, than to regard it as a single through rate to be divided in the usual manner.

Compacts of this kind may increase, but at present they are too exceptional to merit more than passing notice.

As one example of "arbitrary" allowances, a large part of the business from and to local points near large cities really comes under the head of through traffic; the through rates from the West to points within a hundred miles more or less, of New York, for instance, being usually made the same as to New York, and divided as if the freight or passengers were actually taken to and delivered there.

In such case the division is not exactly as the mileage, but it is the same in its effect upon the receipts of the connecting lines as if it were.

210. Certain considerable allowances for terminal charges at points where such charges are heavy are very commonly and very justly deducted from the through rate before the latter is distributed, as notably at New York, where the terminal allowances are very heavy (4 to 5 cents per 100 lbs.), although hardly enough to cover the direct and indirect expense to the terminal road.

In fact the variations and exceptions in the fixing and division of rates are endless, but through them all the general law holds good that all "through" rates between connecting lines are divided precisely *according to* the actual mileage, and to a very large extent directly as the mileage.

211. These facts result in a curious and apparently contradictory law, as respects the through traffic of a new or old road, which it may be highly important that the engineer should understand. That law may be thus expressed:

1. IT IS EXTREMELY DESIRABLE THAT ANY NEW LINE SHOULD FORM A PART OF THE SHORTEST ROUTES BETWEEN IMPORTANT CENTRES OF TRAFFIC.

2. IT IS NOT DESIRABLE, AND OFTEN THE REVERSE OF DESIRABLE,

in themselves they are wholly harmful, whereas extra distance is not.

215. A notable example of these antithetic effects of distance, and of the danger of disregarding them, may be found, among many others, in the old Atlantic & Great Western (now New York, Pennsylvania & Ohio) Railroad. It enjoys the unique distinction of being now, as it was when first built, the longest line in existence even between its three termini—New York in the East, Cincinnati and Cleveland in the West. It has always two, and generally three or four, more favored rivals between each considerable point in the East and every considerable point in the West. Yet even in this extreme case, if its own line had been ten miles longer between Cleveland and Cincinnati and New York it would have been better off. It would then have received $\frac{399}{872}$ or 46 per cent (see par. 220) instead of $\frac{389}{862}$ or 45 per cent on all Cincinnati and New York business, and $\frac{223}{637}$ or 35 per cent instead of $\frac{213}{627}$ or 34 per cent on all Cleveland-New York business, assuming in both cases that receipts were divided strictly according to distance.

216. As it happens, this is, or was until within a few years (the old Atlantic & Great Western is now leased to the Erie), one of the cases in which the division was not strictly as the distance; the Erie Railway having formerly insisted on being allowed a CONSTRUCTIVE MILEAGE of 46 miles from the junction point at Salamanca to its terminus and junction with the Lake Shore & Michigan Southern Railway at Dunkirk: an unjust exaction, which it had power to enforce because it was the only eastern connection of the Atlantic & Great Western. Whereas, therefore, a division exactly according to distance would have given the Erie on Cleveland-New York business $\frac{414}{627}$ or 66 per cent, and the Atlantic & Great Western $\frac{213}{627}$ or 34 per cent, the actual

division was $\frac{414 + 46}{627 + 40}$ or $\frac{460}{673}$ (68 per cent) to the Erie and only $\frac{213}{673}$ (32 per cent) to the Atlantic & Great Western. Nevertheless, in this as in all other cases divisions were ultimately based upon, although not in strict accordance with, the precise relative hauls.

217. From this example the over-hasty conclusion should not by any means be drawn, that a road should lengthen its line of set purpose, for this end alone, for that would probably lead to acts of folly; but it does clearly follow that whenever a better line in all other respects can be thus obtained it will ordinarily be folly not to take it. As it happens, such lines did exist at several points along the Atlantic & Great Western, affording better grades, more traffic, and cheaper work, at the cost of some distance; but unfortunately the original projectors sinned against both of the cardinal principles laid down in par. 211: they neglected the vital end of securing short and favorable connections, but exerted themselves to shorten their own road by striking an air-line wherever possible, at almost any sacrifice of gradients; running it, in literal truth, "over the hills and far away" from traffic. The consequences of such engineering may be read in the financial history of the road—a history which might have been anticipated with certainty in the beginning, and may be counted on with certainty to continue to the end. It has now found its greatest and only real use as a feeder and competing weapon in the hands of the Erie, but considered as a separate property, apart from one or two profitable leases which have alone kept it in as good a position as it has had (see Chap. XXI.), it can never by possibility more than barely pay operating expenses for any period of years; for, however great may be the growth of traffic, and however great the future improvements tending to reduce expenses, other lines also share these advantages, and through rates will continue to fall in proportion, down to the lowest point which affords *the most favored line* a handsome but not exorbitant profit, and way rates likewise will continue to

fall in proportion down to a reasonable but not excessive percentage (usually from 50 to 75 per cent) in excess of the through competitive rates.

218. In a certain important sense, indeed, we may say that all rates are fixed by competition, for the fact that non-competitive way rates do adjust themselves quite closely to the through rates is well determined. In illustration of this fact, which has been

TABLE 93.

STATISTICS OF PASSENGER TRAFFIC, CLEVELAND, COLUMBUS, CINCINNATI & INDIANAPOLIS RAILWAY, 1873–1885.

YEAR.	LOCAL PASS.		THROUGH PASS.		Per Cent Through of Local Rate.
	Av. Haul. Miles.	Rects. Per Mile. Cts.	Av. Haul. Miles.	Rects. Per Mile. Cts.	
1873.....	29.8	3.47	198	2.53	73.0
74.....	27.8	2.83	185	2.55	90.0
1875.....	27.1	2.63	188	2.38	90.5
1876.....	28.3	2.48	192	1.89	76.2
77.....	27.9	2.41	183	2.24	93.0
78.....	27.3	2.42	182	2.10	86.8
79.....	28.6	2.46	186	1.82	73.9
1880.....	29.5	2.39	193	1.82	76.1
1881.....	27.6	2.51	184	1.77	70.5
82.....	28.7	2.60	115	1.78	68.6
83.....	30.5	2.51	121	1.81	72.0
84.....	29.5	2.47	118	1.73	70.0
1885.....	28.9	2.57	121	1.61	62.6

Decrease per cent in through rate in 12 years, 36.4 per cent.
" " " local " " " 25.9 "

Summary of Average Decrease from Average of 1873–5 *to Average of* 1878–81.

Through Freight... 3 y'rs, 1873–75,	.979 ct.	*Local Freight*...... 3 y'rs, 1873–75,	1.766 cts.
3 y'rs, 1879–81,	.593 "	3 y'rs, 1879–81,	1.157 "
A decrease of.....................	.386 ct.	A decrease of......................	.609 ct.
Or, in percentage.................	39⅛ p. c.	Or, in percentage	34½ p. c.
Through Passenger 3 y'rs, 1873–75,	2.487 cts.	*Local Passenger*.... 3 y'rs, 1873–75,	2.978 cts.
3 y'rs, 1879–81,	1.801 "	3 y'rs, 1879–81,	2.455 "
A decrease of........................	0.686 ct.	A decrease of.........................	.523 ct.
Or, in percentage..................	27⅛ p. c.	Or, in percentage..................	13.3 p. c.

TABLE 94.

STATISTICS OF FREIGHT TRAFFIC, CLEVELAND, COLUMBUS, CINCINNATI & INDIANAPOLIS RAILWAY, 1873–1885.

Through Freight.

YEAR.	EAST-BOUND.		WEST-BOUND.		Per Cent West-Bound.	Per Cent Through.	Average Receipts Per Ton-Mile. cts.
	Average Haul. Miles.	Receipts Per Ton-Mile. cts.	Average Haul. Miles.	Receipts Per Ton-Mile. cts.			
1873.........	191	1.14	205	1.34	23.3	62.5	1.175
74	215	.92	214	1.24	26.2	59.2	.984
1875.........	195	.75	223	.86	28.7	59.4	.778
76.........	215	.64	231	.68	26.8	64.7	.650
77.........	202	.67	223	.88	26.2	64.8	.716
78.........	208	.57	221	.84	22.7	67.4	.613
79.........	203	.52	217	.73	26.2	67.6	.565
1880.........	195	.66	212	.73	28.2	64.2	.681
81.........	193	.50	211	.60	35.2	64.9	.532
82.........	184	.59	200	.61	35.4	68.9	.591
83.........	185	.62	202	.71	35.6	65.1	.652
84.........	202	.50	206	.59	37.4	64.9	.525
1885.........	199	.44	207	.51	36.7	68.0	.463

Local Freight.

YEAR.	EAST-BOUND.		WEST-BOUND.		Average Receipts Per Ton-Mile. cts.	PER CENT THROUGH OF LOCAL RATE.	
	Average Haul. Miles.	Receipts Per Ton-Mile. cts.	Average Haul. Miles.	Receipts Per Ton-Mile. cts.		East-Bound only.	Total.
1873.........	119	1.82	98	2.09	1.899	62.7	61.9
74.........	120	1.65	93	2.08	1.776	....	55.4
1875.........	108	1.58	109	1.68	1.622	47.5	48.0
76.........	106	1.42	107	1.44	1.429	....	45.5
77.........	108	1.48	102	1.64	1.538	....	46.6
78.........	116	1.15	98	1.61	1.303	....	47.0
79.........	115	1.15	100	1.34	1.215	....	46.5
1880.........	132	1.00	108	1.34	1.110	66.0	61.3
81.........	105	1.10	112	1.20	1.146	....	46.4
82.........	97	1.17	110	1.18	1.176	....	50.3
83	101	1.12	117	1.03	1.079	....	60.3
84.........	95	1.14	120	.91	1.018	....	51.6
1885	96	1.08	116	.99	1.039	40.8	44.5

Per Cent of Decrease, 1873–1885.

	East-bound.	West-bound.	Av'e.
Through rates..	61.4	62.0	60.7
Local rates	40.7	52.7	45.3

Per Cent of Decrease, 1875–1885.

	East-bound.	West-bound.	Av'e.
Through rates .	41.3	40.7	39.5
Local rates	31.6	41.0	35.9

TABLE 95.

COMPARATIVE THROUGH AND WAY RATES, LAKE SHORE & MICHIGAN SOUTHERN RAILWAY.

(Cents per ton-mile.)

YEAR.	EAST-BOUND.		WEST-BOUND.		Total.
	Through.	Way.	Through.	Way.	
1868......	1.56	3.49	2.02	4.07	2.43
1869......	1.49	3.68	1.78	4.05	2.34
1870......	1.13	2.67	1.53	2.84	1.50
1871......	1.17	2.35	1.18	2.26	1.39
1872......	1.13	2.04	1.49	2.01	1.37

COMPARATIVE RATES, TAKING RATES OF 1868 AS 1.00.

1868......	1.00	1.00	1.00	1.00	1.00
1869......	.954	1.055	.882	.996	.962
1870......	.723	.755	.758	.698	.617
1871......	.750	.673	.585	.556	.572
1872......	.723	.685	.738	.494	.563

Since 1872 the rates have not been made public in this form, for through and way separately.

It will be seen that the non-competitive way rates fall in close sympathy with the competitive rates, and vary more directly with each other than the East-bound and West-bound.

already alluded to (par. 54), a comparison of the course of through and local rates on the Cleveland, Columbus, Cincinnati & Indianapolis Railway is given in Tables 93 and 94, and on the Lake Shore & Michigan Southern Railway in Table 95, which illustrate the fact very strikingly. Few roads publish reports from which such statistics can be obtained, but the law holds substantially true everywhere.

219. From these examples it takes no great intelligence to perceive how inexorable is the law that the line which places itself originally at any serious disadvantage has no escape from the consequences of its folly but to remedy those disadvantages.

Apparent advantages from the general progress in wealth and population and science do not help it at all, since all lines share alike in them. They simply enable it to hold its own, and "its own" is nothing but bare existence. We have in many such lines, as particularly in the line last referred to, a striking evidence of how completely an enormous investment may be thrown away solely and only from bad engineering advice.

220. It may be added, that the through rate is nearly always divided by some even percentage, and consequently trifling differences are not likely to affect the division either way. Thus a line entitled by its exact mileage to receive either $\frac{397}{1000}$ or $\frac{403}{1000}$ would probably receive 40 per cent. If its length entitled it to $\frac{406}{1000}$ it would probably receive 41 per cent. The fractional percentages are sometimes insisted on by the line which happens to hold the stronger position, but usually any advantage of that kind takes the form of some terminal or arbitrary allowance instead of a modification of the percentage.

221. Since the receipts of any one road from competitive exchange traffic vary (1) with the total haul on each unit of traffic, and (2) with the proportion thereof on the home and foreign roads, the effect of any given change in the length of the home road will be different on traffic between all possible traffic points. All that can be done, therefore (or all that is in the least necessary to do), is to form some rude idea of the CENTRE OF GRAVITY of the initial and terminal points of shipment at each end of the line, which will often be quite different for different parts of the line.

Precision in such estimates is unimportant, because the future is almost certain to bring about great changes, and perhaps very speedily. But when two alternate lines are under comparison in other respects, the approximate effect of their differences in this respect also should be determined, with a view of seeing whether they strengthen or weaken, or utterly nullify, the conclusions that would be otherwise reached. That they do the latter, so as to in themselves alone cause the selection of one route instead of another, should be admitted only with the utmost caution.

ences the law is sufficiently exact, as is evident in Table 96, which gives the exact effect on receipts of modifications of 10 and 20 per cent in the home haul.

TABLE 96.

EFFECT OF CHANGES OF DISTANCE ON EARNINGS FROM THROUGH (EXCHANGE) COMPETITIVE TRAFFIC.

Giving the exact effect, and illustrating the essential truth of and amount of error in the approximate rule in paragraph 223.

Effect of 10 *per cent Increase of Distance.*

Per Cent of Original Total Haul on the Home Road.	Corresponding Receipts of Home Road out of $1.00 Rate.	If the *Home* Road were Ten Per Cent longer its Receipts would be—	Per Cent of *extra* Receipts on *extra* Haul to Average.	Sum of Percentages in First and Last Columns.
10	10 cts.	$\frac{11}{101} \times \$1.00 =$ 10.891	89.1	99.1
20	20 "	$\frac{22}{102} \times$ 1.00 = 21.57	78.5	98.5
30	30 "	$\frac{33}{103} \times$ 1.00 = 32.04	68.0	98.0
40	40 "	$\frac{44}{104} \times$ 1.00 = 42.31	57.8	97.8
50	50 "	$\frac{55}{105} \times$ 1.00 = 52.38	47.6	97.6
60	60 "	$\frac{66}{106} \times$ 1.00 = 62.26	37.7	97.7
70	70 "	$\frac{77}{107} \times$ 1.00 = 71.96	28.0	98.0
80	80 "	$\frac{88}{108} \times$ 1.00 = 81.48	18.5	98.5
90	90 "	$\frac{99}{109} \times$ 1.00 = 90.83	9.0	99.0
100	100 "	$\frac{110}{110} \times$ 1.00 = 100.00	None.	100.0

Effect of 20 *per cent Increase of Distance.*

10	10 cts.	$\frac{12}{102} \times \$1.00 =$ 11.765	88.2	98.2
20	20 "	$\frac{24}{104} \times$ 1.00 = 23.07	76.8	96.8
30	30 "	$\frac{36}{106} \times$ 1.00 = 33.96	66.0	96.0
40	40 "	$\frac{48}{108} \times$ 1.00 = 44.44	55.5	95.5
50	50 "	$\frac{60}{110} \times$ 1.00 = 54.545	45.5	95.4
60	60 "	$\frac{72}{112} \times$ 1.00 = 64.284	35.7	95.7
70	70 "	$\frac{84}{114} \times$ 1.00 = 73.68	26.3	96.3
80	80 "	$\frac{96}{116} \times$ 1.00 = 82.80	17.5	97.5
90	90 "	$\frac{108}{118} \times$ 1.00 = 91.53	8.5	98.5
100	100 "	$\frac{120}{120} \times$ 1.00 = 100.00	None.	100.0

FIGS. 7 TO 12, DIAGRAMS ILLUSTRATING THE EFFECT ON RECEIPTS FROM COMPETITIVE THROUGH TRAFFIC OF A LONGER HOME LINE BETWEEN THE SAME TERMINI.

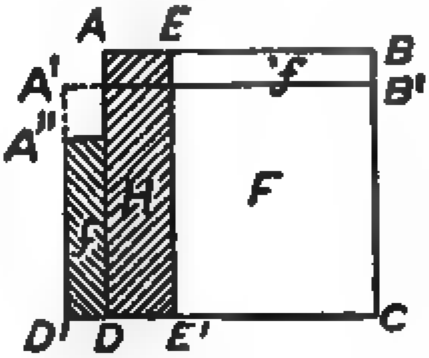

FIG. 7. FIG. 8. FIG. 9.

[*On these diagrams the interpolated mileage on the home road* (*f*) *is assumed to be* ONE EIGHTH *of the* TOTAL *haul.*]

FIGS. 7–10 ONE QUARTER of total haul on home road. FIGS. 8–11 ONE HALF of total haul on home road. FIGS. 9–12. THREE QUARTERS OF total haul on home road.

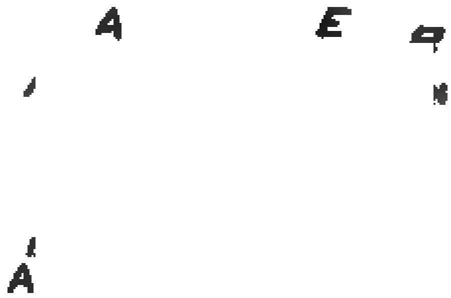

FIG. 10. FIG. 11. FIG. 12.

[*On these diagrams the interpolated mileage on the home road* (*f*) *is assumed to be* ONE QUARTER *of the* TOTAL *haul.*]

Explanation of diagrams, and demonstration, from Figs. 7 to 12, of law stated in par. 222.

225. In each diagram let the base $DC =$ the total haul on any given unit of through competitive traffic, in part over the home road, H, and in part over one or more foreign roads, F.

And let the altitude $AD = BC =$ the average receipt per mile on this unit of traffic

Then will the area $ABCD =$ the total through rate per unit of traffic (less any terminal or other constant deduction), and the areas H and $F =$ the fractions thereof appertaining to the home and foreign roads, respectively.

Assume the total haul increased to $D'C$ by the addition of the distance DD' to the home road. Then, since the total through rate remains the same, we shall obtain a new average rate per mile, $A'D'$, of such amount that the area of the new rectangle $A'B'CD' =$ area of original rectangle $ABCD$.

Furthermore:

Rectangle $AB' =$ gross amount lost by both roads jointly on original haul by decrease in through rate per mile = rectangle $A'D =$ gross amount *gained by home road exclusively* from earnings at decreased average rate on its extra mileage.

But if we assume the earnings of the home road on its original mileage to be unaffected by the addition thereto, then will the rectangles $EB' =$ the gross amount lost by the foreign road through the longer haul at the same through rate, and this area only will represent the *extra* receipts of the home road on its *extra* mileage, which let = rectangle $A''D$.

Then we have, geometrically,

$$\frac{A''D'}{A'D'} = \frac{EB}{AB'}; \quad \text{i.e.,}$$

Net rate per mile realized on home road on added haul (rate realized by home road on original mileage being supposed unchanged) is to average through rate per mile on new and longer haul as original haul on foreign road is to original total haul.

For example: If 25, 50, or 75 per cent of the original haul (before the home line was lengthened) was on the foreign road, the home road will realize (within a trifling error, shown in Table 96) 25, 50, or 75 per cent of the new average through rate per mile on any added mileage, without suffering any such reduction as its connections have to suffer on its *original* mileage.

In practice, the changes of length which the engineer is called upon to consider will ordinarily be so small that the through rate per mile of competitive freight will be but little affected, so that we may say in Figs. 7 to 12 that practically $A'D' = AD$, whence we have the approximate law of par. 222.

TABLE 97.

PROPORTION OF THROUGH AND LOCAL FREIGHT IN EACH CENSUS GROUP OF THE UNITED STATES.

[Computed from Census of 1880.] (Earnings.)

CENSUS GROUP.	Through Freight.	Local Freight.	Total.
I. New England........	69.7	30.3	100.
II. Middle to Indiana....	60.5	39.5	100.
III. Southern...........	58.4	41.6	100.
IV. N. W. Central........	43.8	56.2	100.
V. Louisiana and Ark....	51.5	48.5	100.
VI. Far West...........	39.5	61.5	100.
Total United States.	56.	44.	100.

For more accurate designation of groups see Table 92 and others. Not all the freight here classed as "through" is competitive traffic, by any means.

TABLE 98.

FREIGHT MOVEMENT, THROUGH AND LOCAL, EAST AND WEST, ON PENNSYLVANIA RAILROAD (P. R. R. DIV. ONLY) FOR THIRTY-FIVE YEARS.

(Paying freight only. Statistics exist no farther back.)

YEAR.	TONS CARRIED. 1 = 1,000,000.					TON-MILEAGE. 1 = 1,000,000.				
	Through.		Local.		Total.	Through.		Local.		Total.
	East.	West.	East.	West.		East.	West.	East.	West.	
1851 ...	.005	.008	.008	.005	0.026	......	......	......	......	..
52 ...	.013	.019	.021	.015	0.069	2.35	3.17	6.9	4.2	16 8
53 ...	.036	.038	.049	.037	0.160	8.30	8.27	12.1	11.4	40.0
54...	.050	.043	.089	.054	0.237	12.5	10.6	26.6	11.9	61.6
55 ...	.106	.065	.128	.065	0.365	26.9	16.3	41.7	17.3	102.2
1851-5	.051	.042	.072	.043	0.207	12.51	9.58	21.82	11.20	55.12
1856....	.089	.076	.196	.092	0.454	22.0	19.0	55 4	23.4	119.8
57 ...	.094	.077	.385	.406	0.964	23.5	19.1	67.3	30.8	140.7
58....	.141	.080	.404	.421	1.047	35.0	19.8	75.6	31.7	162.1
59....	.130	.103	.571	.366	1.170	46.5	37.2	69.5	27.3	180.3
60 ...	.176	.100	.642	.429	1.346	63,0	35.7	89.9	26.4	215.1
1856-60.	.126	.087	.440	.343	0.996	38.0	26.16	71.54	27.92	163.62
1861....	0.31	0.08	0.86	0.37	1.63	111.2	28.1	120.9	20.0	280.3
62 ...	0.37	0.13	1.13	0.43	2.06	131.5	45.9	163.8	35.1	376.2
63 ...	0.35	0.13	1.23	0.56	2.27	124.9	45.5	177.7	45.6	393.7
64....	0.32	0.15	1.48	0.63	2.59	115.5	53.0	200.0	52.2	420.6
65 ...	0.30	0.16	1.42	0.67	2.56	108.4	57.6	203.9	50.1	420.1
1861-5..	0.33	0.13	1.22	0.53	2.22	118.30	46.02	173.26	40.60	378.18
1866....	0.32	0.16	1.84	0.86	3.19	113.	58.8	276.	65.0	513.
67....	0.31	0.17	2.21	1.02	3.71	110.	62.0	322.	72.1	566.
68....	0.39	0.22	2.58	1.24	4.43	141.	77.3	373.	84.8	676.
69 ...	0.47	0.23	2.82	1.47	5.00	169.	83.5	402.	98.9	753.
70....	0.54	0.23	3.07	1.58	5.43	104.	83.	439.	110.	826.
1866-70.	0.41	0.20	2.50	1.23	4.35	145.4	72.9	362.	86.2	667.0
1871....	0.71	0.31	3.70	1.85	6.58	254.	113.	533.	113.	1012.
72....	0.79	0.36	4.22	2.47	7.84	283.	130.	625.	152.	1190.
73....	0.87	0.32	5.48	2.54	9.21	312.	114.	821.	137.	1385.
74....	1.07	0.30	4.92	2.34	8.63	381.	108.	764.	119.	1373.
75....	1.00	0.35	5.39	2.37	9.12	358.	126.	863.	133.	1479.
1871-5..	0.89	0.33	4.74	2.31	8.27	317.6	118.2	721.2	130.8	1287.8
1876....	1.32	0.29	5.79	2.52	9.92	473.	105.	915.	136.	1630.
77....	1.02	0.29	5.71	2.72	9.74	364.	103.	869.	159.	1495.
78....	1.45	0.29	6.20	3.01	10.95	519.	103.	936.	175.	1732.
79...	1.69	0.38	7.59	4.01	13.68	605.	137.	1138.	257.	2137.
80 ...	1.58	0.49	8.51	4.79	15.36	565.	174.	1230.	329.	2298.
1876-80.	1.41	0.35	6.76	3.41	11.03	505.2	124.4	1017.6	211.2	1858.4
1881....	1.64	0.57	10.12	5.91	18.23	586.	203.	1452.	414.	2655.
82....	1.35	0.59	11.91	6.51	20.36	483.	213.	1755.	430.	2880.
83....	1.38	0.56	12.47	7.27	21.67	494.	199.	1853.	451.	2997.
84...	1.29	0.53	13.33	7.43	22.58	468.	192.	1938.	484.	3082.
85....	1.68	0.57	13.88	7.91	24.05	612.	209.	1969.	529.	3318.
1881-5..	1.47	0.56	12.34	7.00	21.38	528.6	203.2	1793.4	461.6	2986.4

TABLE 98.—*Continued.*

SUMMARY BY HALF-DECADES.

Year.	Tons Carried. 1 = 1,000,000.					Ton-Mileage. 1 = 1,000,000.				
	Through.		Local.		Total.	Through.		Local.		Total.
	East.	West.	East.	West.		East.	West.	East.	West.	
1851-5..	.05	.04	.07	.04	0.21	12.5	9.6	21.8	11.2	55.1
1856-60.	.13	.09	.44	.34	1.00	38.0	26.2	71.5	27.9	163.6
1861-5..	.33	.13	1.22	.53	2.22	118.3	46.0	173.3	40.6	378.2
1866-70.	.41	.20	2.50	1.23	4.35	145.4	72.9	362.4	86.2	667.0
1871-5 .	.89	.33	4.74	2.31	8.27	317.6	118.2	721.2	130.8	1287.8
1876-80.	1.41	.35	6.76	3.41	11.93	505.2	124.4	1017.6	211.2	1858.4
1881-5..	1.47	.56	12.34	7.00	21.38	528.6	203.2	1793.4	461.6	2986.4

PERCENTAGES AND AVERAGE LOCAL HAUL.

Year.	Per Cents of Total.								Average Haul on Local Freight.	
	Tons.				Ton-miles.					
	Through.		Local.		Through.		Local.			
	East.	West.	East.	West.	East.	West.	East.	West.	East.	West.
1851-5 .	24.5	20.5	34.5	20.5	22.7	17.3	39.6	20.4	30.3	26.0
1856-60.	12.7	8.7	44.2	34.4	23.3	16.0	43.7	17.0	163.	81.0
1861-5..	15.0	5.9	55.1	24.0	31.3	12.1	45.7	10.9	141.	76.5
1866-70.	9.4	4.6	57.7	28.3	21.8	10.9	54.4	12.9	145.	70.2
1871-5..	10.8	4.0	57.3	27.9	24.7	9.1	56.0	10.2	151.	56.6
1876-80.	11.8	2.9	56.7	28.6	27.1	6.7	54.8	11.4	150.	61 9
1881-5 .	6.9	2.6	57.7	32.8	17.6	6.8	60.2	15.4	145.	66.0

226. From the additional receipts thus realized is to be deducted the additional cost of earning it, which we have seen may vary anywhere from 25 to 40 or (for great changes) 50 per cent of the average cost per mile. No absolute profit, therefore, can be realized from longer home-haul of competitive freight, unless the foreign haul is greater than 25 to 40 or 50 per cent of the total. But with any foreign haul whatever there is some credit as well as debit side to the disadvantages of distance for this class of traffic.

227. Let us now see, in continuation of par. 205, how much weight should be probably given to DIFFERENCES OF DISTANCE AS RESPECTS WAY TRAFFIC. Table 92 and various others will show that it is a fairly low estimate to assume 40 passengers or 100 tons of freight as an average train-load, about one half of which (see Tables 97 and 98) will be local traffic, at rates fixed by the mile or at the will of the company. The fluctuations from this average are very great indeed, and a nearer estimate can easily be formed in any particular case. Assuming the above average, however, at 1¼ cents per mile for freight and 2½ cents for passengers, this purely local traffic would net 50 to 62½ cents per train-mile. On the other hand, we have already estimated (Table 89 and par. 195) the actual cost of running an extra mile at from 25 to 50 cents. This sum includes all expenses for running such distance, so that any additional receipts arising therefrom must be credited against it in full.

228. Accordingly, it is plain that whenever way rates are actually determined by the distance alone, any reduction of distance would be very apt even to entail a balance of loss upon the company. For example, it would undoubtedly entail a net loss on the New York Central Railroad, from their way business alone, to shorten their line by several miles, even if it could be done without cost to them, provided all their business, "way" as well as "through," had to be transported over the new line; for 60 cents would be a very high estimate of the actual cost of running extra distance on that road. On the other hand, taking an average train-load (on main line only) of 100 passengers, and assuming the very low proportion of one half as that on which the receipts are fixed by the legal limit of 2 cents per mile, we have an average gross loss of 100 cents per train-mile, or a net loss of 40 cents for every mile cut out of the line. And if the gross loss had been but 10 cents instead of 100, it would have operated to reduce the value of any saving of this distance by so much, although not entirely destroying it.

229. All way traffic, however, is not by any means rated solely by the mile; nor would any railway think of attempting to so

rate it, even if it had the power to do so, without destroying business. Tables 93–5 clearly show this. Table 98, showing the enormous and growing proportion which local traffic makes of the total traffic of a line like the Pennsylvania even, which is often thought of as chiefly a through trunk line, makes it still clearer that it is impossible that local traffic should be all so rated. And yet a line 110 miles long instead of 100, between two given points, will, or can be made to, derive some addition to gross receipts without working either hardship or injustice. The local passenger rates would be perhaps $3.30 instead of $3 —a difference which those who may be called floating or occasional travellers (those making one or two or ten trips a year) can well afford to pay, and would pay, probably without feeling the difference. If we estimate the total extra cost of running the 10 miles extra distance at $3, which would ordinarily be ample, it would require but 10 such passengers per train to wholly counterbalance the cost of running the extra distance. That road would be the exception perhaps which did not average 10 such passengers per train, and substantially the same condition of things exists on many roads in freight business also.

For the remainder of the traffic, to which the greater rate for the extra distance would be a real hardship and burden, it is entirely at the discretion of a railway company to do away with the extra burden by special rates based on volume of business furnished; and this is the true and just principle of fixing rates under all circumstances; for the interest both of the stockholders and the general public. A man who travels or makes a shipment over a line once a year is not greatly burdened by even a considerable difference of rates, and it may equitably be collected from him. A constant patron of the line, on the other hand, finds the same difference of rate a very great burden.

230. Thus we seem driven to the conclusion that it is rather worse than money thrown away for any average road to spend money in shortening its line, nor is there any escape from the conclusion that there is only one class of road to which it can, under any circumstances, be any great object to do so;—those,

namely, whose traffic is mostly hauled over their own lines exclusively, while at the same time the rates on a large portion of it are directly or indirectly fixed by competition, as on two or three of the great trunk lines. A large non-competitive way traffic alone may entirely neutralize the pecuniary value to the company of saving distance.

231. But these conclusions, although undeniably true, should be acted upon with even greater caution than those already suggested with respect to through business, and only when there is no possible doubt as to the interests of the company. For as a question of public policy the conditions which bring about a credit side to distance have no force whatever, the ultimate loss to the community from an unproductive and avoidable service being the same whether borne directly by the railway company or transferred by it to the general public. And inasmuch as the prosperity of a railway is intimately connected with that of its supporting population, the policy under certain circumstances—perhaps under any circumstances—of thus counting in as a makeweight a possibly avoidable tax (a large fraction of which is, so to speak, spent in collecting it), however fairly distributed and lightly borne, may be questioned, especially as the ability to collect it through absence of competition is, by its very nature, temporary and changeable. Nevertheless a railway is a business enterprise and not a charitable institution, and it has the same right as any private citizen to take every reasonable precaution to secure pecuniary success.

232. The future returns to the investors are always more or less problematical, while the benefit to the public is not problematical, and always far ahead of any possible profit to the investors. It is hardly reasonable to demand, therefore, that railways shall increase their investment for the sake of decreasing the return on that investment paid by the public; and sound policy requires and justifies this at least—that the expenditure should be mainly directed not to shortening the line, but to reducing the gradients or vertical distances, which we shall find to be immensely more important than linear variations in their ef-

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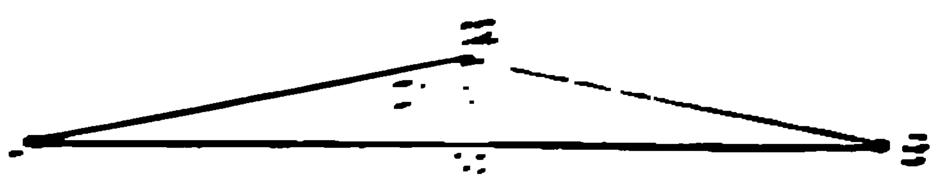
[illegible]

[illegible]



[illegible]

[illegible]

On such a [illegible]
amount [illegible]
[illegible]
The average payment [illegible]
about $13 per head per [illegible]
be a sufficient inducement [illegible]
extreme fluctuations in the [illegible]

A village of coal-miners will produce ten times that traffic at least, and some retired hamlet not a tenth of it.

236. The preceding is independent of the effect of the two miles extra distance to increase receipts as well as expenses on the traffic as a whole. Taking that into account, it needs no further demonstration to show that it must in general be a serious mistake to neglect way points simply to shorten the line, unless the grades are also affected. In the latter case it becomes more doubtful; but taking the country as a whole, not only the private interests of railway corporations but the interests of the general public as well have suffered great disadvantage and loss from contrary practices, while the aggregate railway mileage has been unnecessarily increased; for a slight swerve in the main line will often save a long branch or a longer competitive line.

237. The doubting engineer may safely take the two following as *prima-facie* guides, to be deviated from only as special reason to the contrary appears:

1. Any deviation which will increase THE AVERAGE PER MILE OF ROAD OF TRIBUTARY POPULATION (weighing the latter, of course, in proportion to their revenue-producing capacity) is all but certainly expedient, because it is mathematically demonstrable that the longer line ought then to be for the joint advantage of the community and the railway (see Chap XXI.).

2. Even if the gain be considerably less than this, the deviation may easily be (and probably is) for the interest of the railway, although not in that case expedient in itself, as a question of public policy.

238. All the preceding conclusions as to the comparatively slight importance of distance (and the same is true of all the minor details of alignment) may well lead to ruinous consequences if they are stretched until they crack to support some extended and radical change materially modifying the cost and convenience of transportation, and so discouraging traffic; for it must never be lost sight of, that anything which tends to permanently increase by ever so little the cost to the public of any given service is disadvantageous to all parties, although its disadvantages may be more than made up to one party by the gains; and if the difference be extreme, the danger of permanent disaster to the property is great. The point which it has been sought to bring out is, that even in extreme cases there always is

a credit side of considerable importance to increase of distance —contrary to the idea which prevails to an unfortunate extent, that a short and direct line is the first desideratum, to which almost everything else must bend. On the contrary, it would be hard to put the general rule which should govern action about obtaining a short line in a simpler and safer form than to say that it is the one desideratum about a railway which it is a good thing to have if it costs nothing, but which must give way to other considerations in case of conflict, and is not worth spending much money for.

There are cases—as for instance a line between New York and Philadelphia—where it is of great importance; but the exceptional position of distance as the one element of cost of transportation which is used as a basis for collecting revenue makes such exceptions rare. If the conditions were different—if, for example, we could charge the passengers we did get more, because we had sacrificed the chance of getting some others in order to carry them more quickly—all this special pleading would fall to the ground, and distance would take its true relative position with the other elements of the cost of transportation on the basis of cost alone. But the very fact that this is not the case seems to have had the effect of reversing a reasonable deduction from the premises, in the minds of the more ignorant and thoughtless, by leading to some such hazy chain of reasoning as we noted in the beginning of this chapter.

239. There is another argument, of much the same vague kind as that last referred to, but of a more reasonable and tangible character, which is sometimes brought up as a reason for saving distance, viz., THE "MORAL EFFECT" OF A SHORT LINE in helping to secure traffic. Nor is this argument wholly unjustified, for there are numerous lines throughout the country which do apparently suffer simply from the length of their line frightening away passengers and fast-freight traffic. We may see that this effect is feared by the current fashion of misrepresenting geography in railway advertising circulars.

240. Many lines which are not particularly direct, however,

do not do this, and the prosperity of a single conspicuous line, the New York Central & Hudson River Railroad, will show that there is nothing in distance pure and simple to deter travel until, as in the case of the Grand Trunk Railway in competing for American business, the difference of distance becomes so great as to seriously lengthen the TOTAL TIME of the trip—a result not commonly to be feared from probable engineering modifications of any given line. The enormous proportion of the New York-Chicago travel which the New York Central secures in spite of being the longest of three prominent lines (970 miles against 961 by the Erie and 912 by the Pennsylvania), and in spite of taking passengers 150 miles north before they begin to go toward their destination at all, is sufficient proof that, if a line be equally comfortable and well managed, and makes equally good through time (as all lines do, for the most part, by general agreement, which ticket through at the same price, and as any line can successfully insist on doing when its length is not in excess over 10 or 15 per cent), it will not suffer to any material extent from this cause alone. That the New York Central is no very great sufferer hardly needs further demonstration than may be found in various tables by referring to the Index.

241. The difficulty is (par. 51) that the lines least favored as to distance are generally less desirable in other respects. There are more connections to make, less favorable through-car arrangements, a less number of and slower trains, etc., etc. At the very worst, moreover, this objection only applies to a very small portion, and that the least profitable portion, of the traffic of a road; and it does not apply at all to those small changes, of a few miles more or less, which the engineer is most frequently called upon to consider, and to which this chapter has mainly referred.

242. The conclusions reached in this chapter have rarely been recognized in the practice of engineers, but instances are not wanting where they have been clear enough to operating officers. As one instance of the latter, on the "Pan Handle" road (Pittsburg, Cincinnati & St. Louis) a tunnel near Steubenville, O., saving two miles of distance and much curvature, but costing $300,000, was avoided by a temporary line. When at last means became sufficient to construct it, the general manager of

the line objected to its construction on the ground that, even though the greater part of their traffic was local to the vast Pennsylvania system, the loss from revenue on the two miles saved would far more than counterbalance the saving in operating expenses; and proved it so conclusively that the construction was for some years postponed. Subsequently, on account of the exceptionally commanding position of the Pennsylvania roads, it was believed that the old distance could be considered as constructively still existing so that this loss would not arise, and the tunnel was built. Whether or not this expectation has been maintained the writer cannot state, nor does it affect the force of the example.

CHAPTER VIII.

CURVATURE.

243. It is the peculiarity of curvature that all its disadvantages lie upon the surface, visible to every eye and comprehensible by every mind. A heavy grade is very unobtrusive. The most skilful and observant eye cannot detect differences of grade which decrease by a large percentage the operating value of the line. But curves attract instant attention, and their disadvantages appeal even more strongly to the imagination of the inexpert than to the instructed judgment of the engineer. A visible defect or

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* This illustration the writer borrows from the heading to a chapter on "Railway Construction" of an English engineering work. Whether or not it is a mere fancy sketch he cannot say; but it at least has no little verisimilitude to not a few actual works. The question naturally arises, what the curve in the foreground is for, especially if the steeple in the middle distance is a hint of a town, or, if a curve was deemed necessary, why it was not made a little longer. There may likewise be found in the picture a hint as to the extent to which a larger expenditure for construction necessarily implies a better line. The further moral which the picture is calculated to teach may be left to the ingenuity of the reader.

danger is always more keenly appreciated and dreaded than one which it requires special training to detect; and since there is always a natural tendency to correct the faults which every one sees and to forget the faults which no one thinks of, it is evident that this simple fact must always have a powerful if undetected influence while human nature remains what it is.

244. And when we come to consider what are the more solid objections to curvature, we find at once that a formidable and undeniably true list of objections to it may be made, consisting of many counts ; as thus :

1. *It causes a considerable loss of power* and considerably more wear and tear of rolling-stock and road-bed, thus increasing expenses.

2. *It does or may limit the length of trains*, and thus still more increase expenses.

3. *It causes a considerable expense for extra watchfulness and track-walking*, and thus indirectly still more increases expenses.

These three are what may be called the definite and positive objections to curvature. We can estimate them with some degree of certainty and exactness. But there are still others which are essentially indeterminate, and which for that very reason it behooves us to examine into the more closely, lest the haze of doubt which unavoidably surrounds them should on the one hand unduly obscure them, or, on the other, have a mirage-like effect, magnifying them into undue proportions. Among these causes are :

4. *The danger of derailment is increased*, and the consequences of such derailment when it occurs are more likely to be serious.

5. *The danger of collision is increased* by the obstruction of the view.

6. *There is more difficulty in making time*, and thus passenger travel is likely to be affected.

7. *It injuriously affects the smooth riding of cars*, and thus deters travel.

8. *It impresses the imagination of travellers with a feeling of danger*

even if none exists, and thus in a third way affects travel unfavorably; and, finally,

9. *It is more or less an obstacle to the use of the heaviest and most powerful types of engines.*

This is a formidable indictment, indeed, and when it is extended from curvature in the abstract to sharp curvature as against easy curvature it becomes still more so; for there is then more wear and tear, more danger of limiting trains and more injurious effect upon the safety and speed of trains, the comfort of travellers and the reputation of the line.

245. It is therefore not unnatural that a very general course of reasoning on the question should be: "Each one of these objections to curvature amounts to something; plainly, therefore, in the aggregate they must amount to a great deal, although no one can ever determine exactly how much. If the curvature be sharp they will be several times more serious, and in fact will then become entirely inadmissible for such a line as ours." Thence may follow, perhaps too quickly, a conclusion in the form of an order to the engineers who are to examine the country, to the effect that "the minimum radius of curvature permitted on this line will be," etc.—an order from which thereafter there will be no retreat.

246. Notwithstanding this plausible reasoning and formidable indictment, it may be said at once that investigation seems to indicate that the prevailing error in respect to curvature among engineers is too great dislike of curvature, and especially of sharp curvature, and too great readiness to spend money to avoid it, although a few go to great extremes in the other direction. This conclusion seems to necessarily result from analysis in detail of the weight to which each of the above objections is entitled; but without presupposing this, and abandoning all prepossessions in either direction, we will consider each objection to curvature as impartially as possible, beginning with what may be called the indeterminate or imaginative (but not therefore imaginary) objections, 4 to 9, which cannot be reduced to a valuation in dollars and cents.

THE DANGER OF ACCIDENT FROM CURVATURE.

247. Railway accidents come from a great variety of causes, of which curvature is one. How great a cause it may be is made difficult to determine by the fact that accidents are rarely reported as directly chargeable to curvature, its effect being rather to aggravate them, or to prevent timely discovery that there is danger of accidents from other causes, than to cause them itself.

Nevertheless we can determine certain maximum and minimum limits for its possible effect as a contributing or aggravating cause of accidents. The total number of accidents to trains per year, of sufficient seriousness to get into the newspapers, as shown by the best available statistics (which are very imperfect), is given in Table 99 for some thirteen years past, with some further details as to accidents in Table 100; and by comparison of these statistics for the eight years ending with 1880, accidents appear to have occurred very nearly at the following rate, for the railway system existing in 1880:

Collisions,.	400,	causing	120	deaths	and	430	injuries.
Derailments, ...	800	"	150	"	"	530	"
Other train accidents,	80	"	30	"	"	40	"
	1,280		300			1,000	

Of the collisions, about 5 per cent are crossing collisions, not likely to be affected by curvature. It is possible to conceive, however, that any one of the 400 collisions might be injuriously affected, if not caused, thereby.

Of the derailments, about

25	per cent	come	from	broken or loose rails,
8	"	"	"	cattle on track,
5	"	"	"	washouts,
12	"	"	"	accidental and malicious obstruction,
16	"	"	"	misplaced switches, and
34	"	"	"	other miscellaneous causes not likely to be affected in any way by curvature.
100 per cent in all.				

TABLE 99.

NATURE AND CAUSES OF THE MORE SERIOUS TRAIN ACCIDENTS IN THE UNITED STATES FOR 13 YEARS, 1873–1885.

Total number of accidents covered by the record:

Collisions	5,099,	of which are unexplained	123	2.4	per cent.
Derailments	9,065,	" " "	2,850	31.4	" "
Other	769		....	....	
	14,933		2,973	19.9	per cent.

The percentages of each cause of accident above are so computed as to eliminate the effect of the "unexplained" accidents thereon, by assuming that the proportion of causes for the "unknown" collisions or derailments is the same as for the known.

The totals and percentages have been computed from a record kept by the *Railroad Gazette*, from which the last thirteen columns (with correction of a number of errors) is taken directly. The table is made up merely from the accidents which get into the leading newspapers, and is very incomplete even as respects those, but probably the omissions are in about uniform proportion for each cause.

TABLE 100.

CASUALTIES CAUSED BY THE DIFFERENT CLASSES OF ACCIDENTS FOR SEVEN YEARS.

Killed.

	In Collisions.	In Derailments.	In Other Acc.	Total.
1885...........	158	141	8	307
1884...........	172	192	25	389
1883...........	227	229	17	473
1882...........	177	200	3	380
1881...........	209	190	15	414
1880...........	156	143	16	315
1879...........	94	97	4	195
Average.....	170	170	13	353

Injured.

	In Collisions.	In Derailments.	In Other Acc.	Total.
1885...........	547	963	20	1,530
1884...........	624	1,062	74	1,760
1883...........	716	1,145	49	1,910
1882...........	578	975	35	1,588
1881...........	565	995	37	1,597
1880...........	412	714	46	1,172
1879...........	286	389	34	709
Average.....	533	892	42	1,467

Of the 1,217 accidents reported in 1885, 193 caused the death of one or more persons each, while 282 caused injury to persons but not death; a total of 475 accidents, leaving 742, or 61 per cent of the whole number, in which there was no injury to persons considered serious enough for record.

The accidents recorded in 1886 were about three for every 1,000,000 train miles, and were divided, according to their nature and the classes of trains, as follows:

ACCIDENTS.	Collisions.	Derailments.	Other.	Total.
To passenger trains..............	47	247	51	345
To a passenger and a freight....	102	....	..	102
To freight trains................	315	434	21	770
Total.........................	464	681	72	1,217

Allowing two trains in each collision, this shows accidents to a total of 1,681 trains, of which 494, or 29 per cent, were passenger trains, and 1,187, or 71 per cent, were freight

trains. This is *very materially* less than the true proportion of freight-train accidents, if accidents of all kinds were included, but it includes a large proportion of those involving loss of life or very serious damage.

Classified by months, the aggregates of the reported train accidents of the six years 1880–1885 (7,949 in all) were:

Winter Months.	Spring Months.	Summer Months.	Fall Months.
Dec. 687	March, 620	June, 438	Sept. 770
Jan. 882	April, 490	July, 556	Oct. 789
Feb. 812	May, 483	Aug. 705	Nov. 717
Total...... 2,381	1,593	1,699	2,276
Per cent. . 30.0	20.0	21.3	28.7

248. There were in the United States in the year 1880 about 90,000 miles of railroad in operation, employing about 450,000 men, and over which some 5,000,000,000 passenger-miles were run each year and perhaps 2,000,000,000 or more employé or free-pass miles, counting both passenger and freight service, the number of freight trains being at least three times greater than passenger trains.

The number of curves will average considerably over one per mile, as shown in the following Tables 101 to 104 (see especially summary to Table 102, page 263), or say at least 128,000 for the whole United States. This is almost certainly not an over-estimate.

249. Performing, then, the simple arithmetical operation of dividing 128,000 curves by 1280 annual accidents and by the given number of deaths and injuries, we find that if ALL train accidents which are serious enough to get into the newspapers were justly chargeable to curvature and to nothing else, there would be on an average one such accident per year for every 100 curves, one death for every 427 curves, and one injury for every 128 curves. To present the meaning of these figures in a clear way: If all train accidents were caused by curvature alone, there would on any one given curve be an accident of some kind worth notice in the public press once in 100 years, a passenger or employé killed once in 427 years, and a passenger or employé injured once in 128 years.

250. Such an exaggeration of the effects of curvature, however, is of course wholly beyond reason. It does not appear probable from the record of Tables 99 and 100 that more than half the individual accidents are of such a nature as to have been at all modified or affected by curvature, and of those which are likely to be at times so affected—such as collisions, broken rails, cattle on track, washouts, landslides, breaking in two of trains, etc., etc.—a large percentage are well known to arise from causes which the alignment would not greatly affect, such as frogs, misplaced switches, accidents to running gear, etc., and others are only likely to be aggravated by curvature. It is extremely doubtful, therefore, if more than 30 or 40 per cent of train accidents are in any measurable degree modified or affected by curvature; and in many of these the effect is so slight or so doubtful, that if we were to assume that from 15 to 20 per cent of all accidents are wholly caused by curvature, it would probably be giving it its full weight. It will be safer, however, especially as our record is not entirely satisfactory, to assume as a mean of possible extremes that 25 per cent of the accidents are caused by curvature, and curvature alone.

251. In that case we shall have on any one particular curve, and caused by that curve—

A train accident serious enough to be mentioned in the newspapers once in 400 years:

A passenger or employé killed once in 1708 years;

A passenger or employé seriously injured once in 512 years.

If we make, now, some simple computations in compound interest (Table 17, p. 80) we reach some rather surprising results:

We find that if we were to invest one dollar at 4 per cent compound interest at the time of construction we should have $6,506,088 to repair the damage arising from the first serious accident occurring on any given curve, and caused by the fact that it was a curve instead of a straight line; $526,201,500 with which to heal the wounds of the first man injured; and a sum an innumerable number of million times greater than the last again (being what it would amount to at compound interest in

1196 years) as a fund wherewith to assuage the grief of the dependent survivors of the first man killed.

Change these figures as we will, and keep within the bounds of reason, and we shall yet find the result substantially the same.

252. Nevertheless, an accident of the most terrible description may happen within a week on any curve, and be directly caused thereby. On some one of the 128,000 curves in the United States it probably will. Accidents of some gravity are continually reported which appear to have been due to or to have been aggravated by curvature, and more than one such per day must happen in the United States by our assumptions. It is also undeniable that all curves are not by any means equally dangerous. When very sharp and on heavy grades they are materially more dangerous than elsewhere. But on the whole, and within the limits of ordinary and reasonable practice, it would almost appear, as if, even it the question were simply curvature or no curvature, the only proper conclusion would be that the question of safety was not entitled to any weight whatever in deciding on the line to be adopted or the expenditure to be incurred. Only when all other considerations were equally balanced should it be made the ground of a decision.

253. But the bald question, curvature or no curvature, never is the question before the engineer. The general character of the line is irrevocably fixed by the topographical conditions. He is not called upon to decide between the crooked solid line and the straight dotted line in Fig. 15, but between a little more

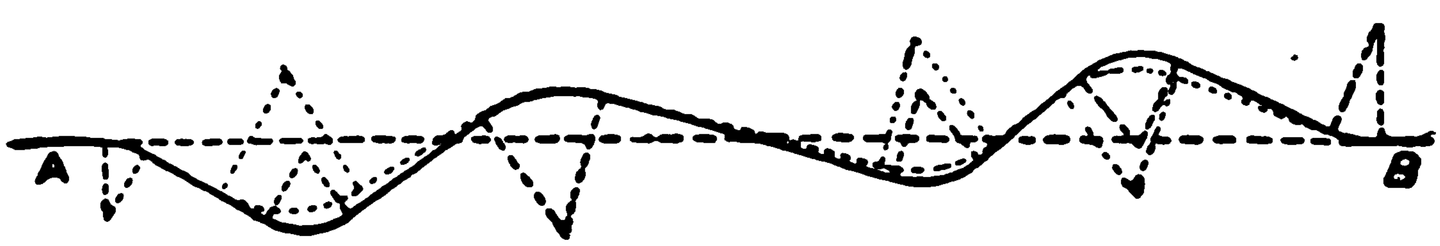


FIG. 15.

and a little less curvature as indicated by the solid and nearly parallel dotted line.

If we could eliminate ALL curvature from railways we might perhaps decrease by 25 or 50 per cent the danger to life and

property. But this is practically impossible; and as between the common case—such alternate lines as are shown in Fig. 15, —let the reader pause for a moment and intelligently consider, *first*, what the probabilities are of an accident on either line due to all its curvature, and, *secondly*, what the danger amounts to of an accident on the one line due to the difference in its curvature from the other? For example, we have in Fig. 16 a view of one of the famous accidents of 1885 (the Monte Carlo disaster), which may be said to have been entirely chargeable to curvature in one sense, because the crookedness of the line prevented the two approaching trains from seeing each other, and this on a line where enormous sums were spent to avoid curvature or to increase its radius, and on the very top of one of the most costly works for that purpose—the immense retaining-wall shown in that view. How much was the danger of accident diminished by these works below what would have existed had the line been more closely fitted to the contour by throwing it back on to the solid in the view, at the necessary cost of somewhat more and somewhat sharper curvature?

254. This question is so important that it seemed essential to make the facts entirely clear. A natural and commendable aversion to anything which seems to imperil life and limb may lead to a dissent from the above conclusions on general principles, as somewhere involving a fallacy, but that they are practically true seems to be proved positively in another way—by the immunity from accident which many very crooked lines enjoy in common with more fortunate rivals, and by the fact that the number of accidents is certainly no greater (in fact it appears from the last (1880) census to be some 18 times less) in the States east of Ohio which have two or three curves to the mile, than in the States west of Ohio which have a curve only every two or three miles, as an average.

255. Unfortunately, from the very fact that curvature plays so small a part as a cause of accident, no general statistics can be given as to the number of cases in which it does have an influence; but a very interesting little volume by Charles Francis

the last accident recorded was not looked for, because the draw was rarely open; and in the same way it is probable that the greater feeling of danger and more constant caution which springs from the existence of curvature, and more especially of much curvature, makes it in some measure a safeguard against accidents as well as a cause thereof. Only in this way can be explained the undeniable safety with which, as a matter of fact, numerous very crooked roads are operated.

257. To illustrate this possible danger from carelessness: There are several hundred miles of the Union Pacific Railroad on which there is practically no break of either line or grade, but trains rise into view on the horizon as at sea. As a very natural consequence, it was at one time, and perhaps in less degree is yet, the custom to operate the road with almost entire indifference to time-tables or train-orders. When an opposing train "hove in sight" both made for the passing point which happened to be nearest between them, and if their idea as to where this point was happened to be different, one or the other would "back out." Such conditions as these seem to afford the *ne plus ultra* of safety, yet if it prevailed on all railways it may be gravely questioned whether it would on the whole add much, if anything, to the average safety of railway travelling; for the feeling of security and habit of carelessness which would thus be engendered in employés of every grade would be apt to lead in emergencies to the most terrible consequences. Such contingencies, for instance, as dense fogs or sudden snow-storms or a cinder in the engineman's eye, or a dozen other possibilities, would be almost certain to bring about occasional accidents which, under conditions exacting greater habitual vigilance, would not have occurred.

258. Even in the cases of derailment mentioned in Mr. Adams' book it is difficult to detect much effect from curvature. The disastrous derailment from a broken rail at Carr's Rock, on the Erie Railway, occurred indeed on a sharp curve on the edge of a precipice (on a division where nearly the whole line is of this description); but another one, precisely like it, occurred in

the immediate vicinity, ten years before, on a perfectly straight piece of track, which is something pretty hard to find in that locality. These are the two most serious accidents which have ever (1882) occurred from this cause on that section of the road. In the first instance, on a curve, 24 were killed and 80 injured; in the second instance, on a tangent, only 6 killed and 50 injured; but the difference is due, not to the alignment, but to the difference in the height of the precipice—30 feet in one case and 80 feet in the other.

259. A very common error with regard to broken-rail accidents requires correction here. There is not a particle of evidence—or certainly none of much moment or weight—tending to show that curvature noticeably increases the liability of breakage or even the consequences thereof.

As respects the former, it is almost purely a matter of the condition of road-bed and of chance defects. Thus the records kept by the *Railroad Gazette* show that such accidents are nearly nine times as numerous in the winter months as in the summer, there having been of noticeable accidents caused by broken rails during the eight years 1873–80: In January, February, and March, 268; in July, August, and September, 32.

The consequences of a rough road-bed or of the temperature of the metal, or both, being so very noticeable, it is clearly indicated that it is the hammer-like effect of the locomotive, rather than any direct pressure, which causes the breakage; and this is not increased by curvature: it is rather decreased. On a tangent a train impinges against the rails with a great deal of force from one side to the other alternately. On a curve every truck in the train tends rather to hug the outside rail with the front outer wheel—in a manner shown in Fig. 17, of which we shall speak more fully shortly—both the inner wheels standing clear of the rail; while the driving wheel-base is preserved by the truck from impinging against either rail with anything like its natural force. For these same reasons a broken rail on the inside of a curve is noticeably less likely to cause a derailment than if on a tangent; while a broken rail on the outside, although it is of course greatly more dangerous than on a tangent, is not so much so as might seem—for the reason that, even on a tangent,

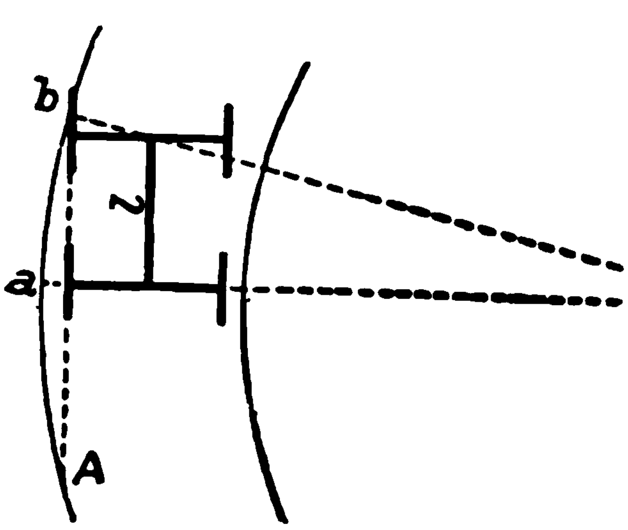


FIG. 17.

some one truck in the train is likely to impinge at just the right spot to cause derailment, and one truck off is nearly as effectual as a dozen to cause a catastrophe.

But if derailment does occur there is certainly more danger on a curve than on a tangent, and in numerous other ways, which appeal very strongly both to the imagination and the judgment, curvature is a real source of danger; and of course the sharper it is, and the more of it there is, the more danger there is. Those who maintain that it should therefore constitute a serious element in the problem of laying out a road have the best of the argument so long as it is confined to generalities. Their case only becomes weak when we consider its force in detail.

260. The truth is that nothing but a standing miracle keeps either curvature or any other of a dozen causes of accident from being a fruitful source of disaster. The marvellous safety of railway travel in the face of such numberless chances for disaster is one of the most impressive triumphs of human care and skill, and it is this fact alone which gives our argument any force whatever. No one could have foreseen it, and hardly any one can fully realize it; but the fact being as it is, true wisdom requires that we should recognize its consequences, and not insist on trusting to the imagination for arguments in a purely practical question.

Mr. Adams has very effectively expressed this marvellous safety in a pithy sentence, by saying, that "the chances of accident in railroad travelling are so small that they are not materially increased by any amount of travelling which can be accomplished within the limits of a human life." He proceeds with the following interesting comparative statistics:

260*a*. "During the four years 1875–8 only 1 passenger was killed from causes beyond his own control in Massachusetts, and only 20 injured. Yet during the year 1878 alone, excluding all cases of mere injury, of which no account was made, no less than 53 persons came to their death in Boston alone from falling down-stairs and 37 more from falling out of windows; 7 were scalded to death. In the year 1874, 17 were killed by being run over by teams, and the pastime of coasting was carried on at the cost of 10 lives more. During the five years 1874–8 there were more persons murdered in the city of Boston alone than lost their lives as passengers through the negligence of all the railroad cor-

porations in the whole State of Massachusetts during the nine years 1871–8, which included the Revere and Wollaston disasters, in which 50 people lost their lives. Neither are the comparative results here stated in any respect novel, or peculiar to Massachusetts: years ago it was officially announced in France that people were less safe in their own homes than when travelling on railroads; and, in support of this somewhat startling proposition, statistics were produced showing 14 cases of death of persons remaining at home and there falling over carpets, or in the case of females having their garments catch fire, to 10 deaths on the rail. Even the game of cricket counted 8 victims to the railways' 10."

260*b*. All these facts agree in indicating the conclusion that although curvature is a considerable source of danger, yet it is even then so little dangerous to life and property that we are not justified in giving any financial weight whatever to this argument against it, unless under peculiar circumstances, or as a makeweight when all other considerations are exactly balanced. The case is entirely different, for reasons we cannot take space to discuss at length, from the defects in operating details which people rightly insist should be corrected even at a large immediate expenditure.

Before proceeding further with the discussion of the question of curvature it may be well to explain just what is meant by the term "the degree of a curve," which we shall have frequent occasion to use, for the benefit of foreign readers if for no others.

261. MEANING OF THE TERM "DEGREE OF CURVE."—The universal method in America of expressing the sharpness of curvature is not by giving the radius, but by the "degree of the curve" or number of degrees of central angle, subtended by a chord of 100 ft.; i.e., by the angular change in direction of the curve in the distance subtended by a chord of 100 ft. If the central angle be 1°, the radius is readily computed as 5729.65 ft., which is the radius of a ONE-DEGREE CURVE, taken in practical work as 5730 ft.

Except as the length of the arc bears a varying ratio to the length of the subtending chord in curves of different radii, it is readily shown geometrically that the radius is inversely proportional to the degree of curvature; and this is so nearly true in fact up to the limit of an 8° curve (within a small fraction of a foot) that it is almost universally customary in the best practice to record the radius of a 1° curve as 5730 ft., and to determine the radius of curves of other "degrees" by the approximate formula,

$$R = \frac{5730}{D}.$$

(To p. 266.)

TABLE 101.

STATISTICS OF GRADES AND CURVATURE ON THE RAILWAYS OF THE NORTH-EASTERN UNITED STATES.

[Computed from the Census Statistics of 1880. See note.]

NEW ENGLAND.

NAME OF ROAD.	Miles of Road.	CURVATURE.			GRADES.			
		Curves Per Mile.	P. C. Curved.	Deg. Per Mile.	P. C. Level.	Rise Per Mile.*	Rise and Fall Per Mile.*	Ruling Grades.
18 Roads, A. to Conn	1,027	1.72	42.0	49.6°	0.0	18.7	12.2	....
19 " Conn. to Nor.	750	1.89	33.3	51.5°	1.3	24.6	15.6	....
20 " Nor to Sum	982	1.67	35.0	38.7°	3.8	19.5	10.5	....
Total, 57 roads	1.859	1.76	36.8	46.6°	1.7	20.9	12.8	....
SINGLE ROADS.								
Boston & Worcester...	44	2.68	40.5	95.0°	2.8	10.4	2.8	30
Boston & Albany.. ...	202	1.55	56.0	72.5°	0.0	9.3	13.7	80
B. & N. Y. Air-line....	51	1.62	34.0	76.0°	6.1	13.5	17.3	60
Concord & Portsm....	40	1.41	37.2	93.0°	3.8	19.0	15.3	80
Central Vermont. ...	120	1.17	37.8	34.5°	0.9	15.7	8.4	42
Totals and av........	457	1.48	41.1	60.2°	3.2	13.6	11.5	....

NEW YORK.

* The column "Rise Per Mile" gives the average *excess* of rise over the fall in one mile. The next column gives the feet of rise *and* fall. Thus, if a road rose 500 ft. and fell 200 in 100 miles, it would be given above as "Rise Per Mile, 3.0." "Rise and Fall, 2.0." The first quantity is an unavoidable necessity, due to difference of level of the terminal.

TABLE 101.—*Continued.*

NEW JERSEY.

NAME OF ROAD.	Miles of Road.	CURVATURE. Curves Per Mile.	P. C. Curved.	Deg. Per Mile.	GRADES. P. C. Level.	Rise Per Mile.*	Rise and Fall Per Mile.*	Ruling Grades.
Morris & Essex........	83.7	1.16	34 0	44.4°	17 8	2 6	16.4	50 +
Phila. & Atl. City.....	54 5	0 42	10 5	6 3°	24 8	0 0	10.7	52 8
Totals and av.......	138.2	0.79	22 2	25 3°	21 3	1.3	13.5	....

PENNSYLVANIA.

NAME OF ROAD.	Miles of Road.	Curves Per Mile.	P. C. Curved.	Deg. Per Mile.	P. C. Level.	Rise Per Mile.*	Rise and Fall Per Mile.*	Ruling Grades.
Cumb. Valley ..	82.2	0.88	17 3	16.6°	9.2	0.7	10.2	49– 58
Del., Lack. & W.......	115.0	2.40	39.2	84.0°	8.6	4 9	18.8	....
Lehigh Valley ..	101.0	2.60	50 0	100 0°	14.4	3.2	12.2	16– 20+
Lew. & Tyrone........	43 4	1.39	26.0	45 3°	20.8	5.0	14.5	71– 48
Montrose	27 2	6.35	49 0	241 0°	3 9	38 4	9 6	95– 74
No. Cent	137.1	2.42	45.5	61.6°	30 3	3.3	6 5	21– 26+
Totals and av	705 9	2.[illegible]	37 8	91 4°	14 5	9 2	12.3	
Penna., Mid. Div......	130 8	1 92	34 3		17 2	2 0	4 6	29– 19
" W. Div	116.7	2 04	45.0		17 4	3.6	15 7	45– 52+
P & N Y Canal ...	94 7	1.76	56.0		41.7	0.3	2 6	20– 38
Perkiomen	38 6	2.18	45 0		11.0	7.5	8 6	45– 43
Phila. & Erie	287 5	1 62	30.2		21 7	0 6	8.7	21– 24+
" (Summit Section)	34 2	2 52	48.3		1.3	9.6	9.4	53–105
Pitts. & Connell. ..	146.5	2.81	50.6		31 5	0 2	11 0	32– 20+
Western Pa	21 0	3.10	46.0		37.4	0.3	11.3	79
" "	63.5	2.93	43.4		47 5	4 2	5 6	52.8
Wilm. & No	69 9	3 86	45 3		22 0	3 4	9.1	57– 53
Totals and av........	1,001.4	2.47	45 3		24.9	3.2	8.7	....

SUMMARY OF NORTH-EASTERN STATES.

Compare Summary of Table 102, with note.

The statistics which appear in this and the following Tables 102, 103, 104 were computed by the writer from time to time from the statistics which were gathered for a large part of the mileage of the United States by the Census of 1880, and thrown into the census reports in an utterly valueless condition, without even being totaled. Not much can be done with them at best, as the blank was not properly prepared; but as they are a record which exists nowhere else, and is very useful in a certain way, they have been in part here given. The reported "maximum grades" must be received with a great deal of suspicion, as some of them are pusher grades and some of them only a few hundred feet long. The striking excess of average grade in the prairie States over what exists in the East is clear enough, and an undoubted fact.

Table 102.

Statistics of Grades and Curvature on the Railways of the North Central States.

[Computed from the Census Statistics of 1880. See note to Table 101.]

Ohio and Indiana.

* See note to Table 101.

TABLE 102.—*Continued.*

MICHIGAN.

Name of Road.	Miles of Road.	Curvature.			Grades.			
		Curves Per Mile.	P. C. Curved.	Deg Per Mile.	P. C. Level.	Rise Per Mile.*	Rise and [redacted] Per Mile.*	Ruling Grades.
Chicago & G. Trunk...	330.5	0 34	6 7	5 5°	23 5	0.3	7.2	54– 51
Det., G. H. & Mil.	189 0	0 51	18 0	12 2°	19.0	0 0	7 8	42 +
J., L. & Sag	236.0	0 62	21 0	11 0°	19 9	1 9	6 8	52 +
Marq., H. & Ont	63 1	2 14	43.4	46 7°	25 8	0 0	23 0	200.
Mich. Air-Line	103 6	1 01	11 3	8 2°	27 5	2 5	7 3	39– 45
Mich. C	270 0	0 61	26.8	18 8°	21.0	0.0	6.5	49– 38
No. C. Mich	61.1	1.16	24 0	19 5°	30 3	4.3	8.1	59.8
Totals and av	1,253.3	0.91	20 2	17.4°	23 9	1.3	9 5	....

ILLINOIS.

IOWA.

* See note to Table 101.

TABLE 102.—*Continued.*

WISCONSIN, MINNESOTA, AND DAKOTA.

NAME OF ROAD.	Miles of Road.	CURVATURE. Curves Per Mile.	P. C. Curved.	Deg. Per Mile.	GRADES. P. C. Level.	Rise Per Mile.*	Rise and Fall Per Mile.*	Ruling Grades.
C., M. & St. P.	194.4	0.58	20.0	14.9°	36.0	0.1	5.4	35- 36
" "	196.4	0.58	15.1	13.3°	17.6	0.4	9.0	50- 53
" "	192.0	0.54	12.0	12.8°	26.0	0.0	10.5	69- 53
" "	202.1	0.70	14.8	13.4°	23.0	6.5	8.3	74- 63
" "	215.4	1.00	23.7	30.2°	21.0	0.9	11.4	63- 52.8
Totals and av.......	1,000.3	0.68	17.1	16.9°	24.7	1.6	8.9	....

SUMMARY OF THE WESTERN STATES.

No. of Roads or Divs.	STATE.	Miles of Road.	CURVATURE. Curves Per Mile.	P. C. Curved.	Deg. Per Mile.	GRADES. P. C. Level.	Rise Per Mile.*	Rise and Fall Per Mile.*
10	Ohio and Indiana	1,304.5	0.83	16.3	16.1°	17.7	1.2	7.8
10	" " "	2,348.7	0.70	15.0	15.9°	22.2	1.2	7.5
7	Michigan...............	1,253.3	0.91	20.2	17.4°	23.9	1.3	9.5
10	Illinois................	982.2	0.57	13.1	6.9°	19.4	1.8	6.4
5	"	1,145.1	0.32	9.7	9.0°	29.7	0.9	8.5
7	Iowa....................	1,525.0	1.36	27.3	36.4°	15.3	3.1	14.9
49	Totals and av........	8,558.8	0.78	16.9	16.9°	21.4	1.6	9.1
99	Ditto, Eastern States, from Table 101. ..	5,372.0	1.88	35.5	55.9°	22.8	4.7	13.0
17	Ditto, South'n States, from Table 103.....	3,511.2	1.10	27.6	31.5°	22.0	1.9	12.4

* See note to Table 101.

The most important moral to be drawn from comparison of this with the preceding table is in the last column of the table, which it seemed impossible to average. viz., in the excessive ruling grades throughout the West, which are considerably heavier than in the East, in spite of the very much easier alignment and less rise and fall. In localities it was impossible or very difficult to avoid this, owing to a succession of long low ridges extending for great distances in each direction; but for the most part it is due to bad judgment in location, in avoiding curvature and loss of distance at any sacrifice of grade, whereas the reverse should be the rule. See Chapter XX.

TABLE 103.

STATISTICS OF GRADES AND CURVATURE ON THE RAILWAYS OF THE SOUTHERN STATES AND MISSOURI.

[Computed from the Census Statistics of 1880. See Note to Table 101.]

Name of Road.	Miles of Road.	Curvature. Curves Per Mile.	Curvature. P. C. Curved.	Curvature. Deg. Per Mile.	Grades. P. C. Level.	Grades. Rise Per Mile.*	Grades. Rise and Fall Per Mile.*	Grades. Ruling Grades.
VIRGINIA.								
Atl., M. & O.	408.6	1.6	36.3	57.5°	15.5	4.1	13.9	80–70 —
Ches. & O.	419.6	2.4	47.0	62.0°	13.5	1.2	13.5	70 ±
Rich. & Dan.	140.6	....	33.8	38.0°	......	2.7	12.4	60
R., F. & Potomac.	81.7	1.0	27.0	30.0°	2.7	1.1	10.2	116–55
Totals and av.	1,050.5	1.7	36.0	46.9°	10.6	2.3	12.5	
NORTH AND SOUTH CAROLINA AND GEORGIA.								
C., Col. & Aug.	191.0	1.05	40.6	36.0°	9.9	1.8	22.9	60–67
Ga. RR. & B.	171.0	0.85	33.5	31.3°	41.0	5.3	10.5	39.6
Macon & B.	188.0	0.33	16.0	9.6°	......	2.0	5.4	75
Totals and av.	550.0	0.78	30.0	25.6°	25.4	3.0	12.9	
KENTUCKY AND TENNESSEE.								
Cin. So.	335.9	1.92	35.2	55.4°	13.4	0.6	15.6	60 —
Eliz., Lex. & B. S.	102.0	1.93	29.5	52.9°	15.4	2.8	15.3	60–66
L. & N.	113.5	0.81	19.4	16.9°	29.0	0.3	11.1	70–53
"	71.3	0.48	14.0	13.9°	22.0	0.8	16.7	70–70
Memph. & C.	272.0	0.66	17.0	16.6°	15.2	0.8	12.9	52.8
Mobile & O.	472.0	0.80	31.3	20.2°	25.5	0.6	7.2	40–30
St. L. & S. E.	135.2	0.88	20.0	22.9°	12.5	0.2	17.5	216–90
Totals and av.	1,501.9	1.07	23.8	28.4°	19.0	0.9	13.8	
MISSOURI.								
Bruns. & Chill.	79.7	0.76	14.7	22.7°	46.0	1.3	5.6	52.8
Burl. & S. W.	82.7	1.70	38.0	55.3°	12.0	2.3	17.3	68.6
Cape G. & St. L.	40.0	0.20	4.5	4.6°	51.6	0.0	1.7	16–11
H. & St. Jo.	206.4	0.76	25.0	17.8°	20.0	1.7	16.9	80–80
Totals and av.	408.8	0.85	20.5	25.1°	32.4	1.3	10.4	

TABLE 103.—*Continued.*

SUMMARY OF SOUTHERN STATES.

No. of Roads or Divs.	STATE.	Miles of Road.	CURVATURE. Curves Per Mile.	P. C. Curved.	Deg. Per Mile.	GRADES. P. C. Level.	Rise Per Mile.*	Rise and Fall Per Mile.*
4	Virginia	1,050.5	1.70	36.0	46.9°	10.6	2.3	12.5
3	N. and S. C. and Ga.	550.0	0.78	30.0	25.6°	25.4	3.0	12.9
6	Ky. and Tenn.	1,501.9	1.07	23.8	28.4°	19.0	0.9	13.8
4	Missouri	408.8	0.85	20.5	25.1°	32.4	1.3	10.4
17		3,511.2	1.10	27.6	31.5°	22.0	1.9	12.4

* See Note to Table 101 and Summary to Table 102.

In Holland, which has the levellest railways in Europe, 62 per cent is level, and only 27 miles out of 945 on grades between 0.5 and 1.5 per cent.

In Germany 25 per cent of the mileage is between 0.5 and 1.5 per cent, and a little over 25 per cent curved.

In Norway a little more than 50 per cent is curved, and 37½ per cent has grades between 0.5 and 1.5 per cent.

TABLE 104.

CURVATURE PER MILE ON VARIOUS RAILWAYS IN THE ROCKY MOUNTAIN REGION WHICH HAVE A GREAT AMOUNT OF CURVATURE.

[Computed from Census Statistics of 1880.]

ROAD.	Miles.	Av. Deg. Per Mile.	ROAD.	Miles.	Av. Deg. Per Mile.
Cent. Pac. (from San Francisco west.)	134	32.0°	Colo. Cent	34	420.0°
	105	151.0°	" "	11	327.0°
	83	93.0°	Virg. & Truckee	22	278.0°
	135	16.0°	Utah & No	100	30.5°
	121	39.5°	" "	105	20.9°
	116	48.5°	Union Pac.	65	59.2°
	178	27.3°	" " West End	31	43.0°
Average	872	52.0°	Texas Cent.	143	24.7°
			So. Pacific	142	63.6°

More commonly yet, the radius is taken direct from a table, but nothing is ever done with it in practical field-work, and it is only of importance for recording on maps or for use in solving problems.

262. Among English engineers curves are usually defined as of so many chains (66 ft.) radius. The radius of a 1° curve in chains is $\frac{5729.65}{66} = 86.813$ chains, so that the one method of designation may be converted into the other by the formulæ,

$$R \text{ in chains} = \frac{86.813}{D}, \quad \text{and} \quad D = \frac{86.813}{R \text{ in chains}}.$$

263. Continental engineers designate curves by the radius in metres. The radius in metres of a 1° curve being $\frac{5729.65}{3.2804} = 1746.4$ metres, we have, for converting the one method of designation into the other, the similar formulæ,

$$R \text{ in metres} = \frac{1746.4}{D}, \quad \text{and} \quad D = \frac{1746.4}{R \text{ in metres}}.$$

264. American engineers, and those adopting American practice, when working with the metric system, use, as the unit chord, a chain of 20 metres (65.61 ft.) divided into 100 links of 2 decimetres (.656 ft.) each. The radius of a curve having 1° of central angle for a chord of 100 of any unit is 5730 (5729.65) *of that unit*, so that the radius in metres of a 1° metric curve is $5729.65 \times 0.2 = 1145.93$ (1146) metres, or *one fifth* as many metres as there are feet in the radius of a 1° foot curve—as is natural from the fact that there are only one fifth as many units in the chord.

265. In stationing under the metric system, however, the best practice is to use 10-metre stations, setting stakes at every other station only (or 1 chain apart) on tangents and easy curves, and at every station (or half-chain) on sharp curves. In practice this produces little inconvenience.

266. The radius in feet of a 1° metric curve is $\frac{65.61}{100}$ of the radius of a 1° "foot" curve, or a little ($1\frac{1}{2}$ per cent) less than $\frac{2}{3}$ (.667) and a little (4.6 per cent) more than $\frac{5}{8}$ (62.5), either of which vulgar fractions may be used for approximate inter conversions.

267. Whether with English or metric measures, on sharper curves than 8° or 10°, the chord becomes so much shorter than the subtended arc that it becomes inaccurate to assume the radius as $\frac{5730}{D}$. To obviate this difficulty, it is now becoming usual in the best practice to run in curves sharper than 8° with HALF the usual unit chord, or 50 ft., and to run in curves sharper than 16° with ONE FOURTH the usual unit chord. It then becomes literally true, to the nearest even

foot, that the radius of all curves, of whatever degree, is given by the formula $R = \frac{5730}{D}$.

It is expedient for practical reasons to set stakes thus frequently on sharp curves, so that this practice involves no inconvenience.

It is rarely necessary or expedient, in practical location, to use other than even degrees (or, at most, even half-degrees) of curvature, except in "closing curves," to connect with other lines, and except that certain degrees which contain an even number of minutes (as 50′, 1° 40′ (100′), 3° 20′ (200′) curves) are, for practical convenience in the transit work, sometimes preferred.

Table 105 gives the radii in feet, chains, and metres of all the curves below 30° which are much used for either metric or English measures. We now resume consideration of the various objections to curvature.

TABLE 105.

RADII OF CURVES OF VARIOUS DEGREES IN FEET, CHAINS, AND METRES.

Degree of Curve.		Curves run by English Measures.			Curves Run by Metric Measures (20 M. Chain).	
		Radius in Feet.	Radius in Chains.	Radius in Metres.	Radius in Metres.	Radius in Feet.
0° 30′	Unit Chord—100.	11,460	173.626	3,492 8	2,291.86	7,519.2
0° 50′		6,876	100.408	2,095.7	1,375.12	4,511.5
1°		5,730	86.813	1,746.4	1,145.93	3,759.6
1° 40′		3,438	52.089	1,047.8	687.56	2,255.8
2°		2,865	43.406	873.2	572.96	1,879.8
2° 30′		2,292	34.726	698.6	458.28	1,503.8
3°		1,910	28.938	582.1	381.98	1,253.2
3° 20′		1,719	26.044	523.9	343.78	1,127.9
4°		1,433	21.704	436.6	286.48	939.9
5°		1,146	17.363	349.3	229.19	751.9
6°		955	14.469	291.1	190.99	626.6
7°		819	12.402	278.1	163.70	537.1
8°		717	10.852	218.3	143.24	470.0
9°	Unit Chord—50.	637	9.646	194.0	127.33	417.7
10°		573	8.681	174.6	114.59	376.0
11°		521	7.892	158.8	104.18	341.8
12°		478	7.236	145.5	95.50	313.3
14°		409	6.201	124.7	81.85	268.5
16°		358	5.426	109.1	71.62	235.0
18°	Unit Chord—25.	318	4.823	97.0	63.66	208.9
20°		286	4.340	87.3	57.30	188.0
24°		239	3.618	72.8	47.75	156.6
30°		191	2.894	58.2	38.20	125.3

DIFFICULTY IN MAKING TIME.

268. It is beyond dispute that the addition of a sufficiently great amount of sufficiently unfavorable curvature will seriously cripple any line. The curvature is objectionable not alone for fast passenger trains but for freight trains also, for it is fully as difficult and as dangerous to run freight trains over sharp curves at 25 or 30 miles per hour as passenger trains at 60 miles per hour, owing to the difference in their mechanical construction, and yet with each alike such speeds are often necessary.

Here, as elsewhere, however, the true question before us is not "Does the difficulty exist?" but "How great is the difficulty, and what are its limits?" Considering the question in this light, and remembering that we are not now speaking of nor considering cost, but only physical possibilities, experience seems to indicate that, up to reasonable amounts of 8° or even 10° maximum curvature (717 to 573 feet radius) this difficulty is not one which results in very serious consequences; for lines which are little less than a succession of such curves have as fast schedules and make as good time and connections as more favored lines. On curvature of shorter radius the centrifugal force becomes so great that either the speed must be checked, or the additional pressure against the outside rail becomes objectionable.

269. In the days of hand-brakes and iron rails this necessity of checking speed on sharp curves was (or would have been) a serious obstacle to habitual fast running, but since the introduction of air-brakes and steel rails a train can be checked up slightly with such a very trifling loss of time—and if it should chance to be omitted, the consequences are so much less likely to be disastrous—that, within the limits of choice which are ordinarily open to the engineer, this question of making time is much less likely than heretofore to be seriously affected by either the amount or the radius of curvature. Since the introduction of steel rails, the question now chiefly concerns passenger traffic, any curve of less than 20° laid with steel (and, in fact, with

properly designed engines, much sharper curves) being safe (we are now considering nothing else) at ordinary freight-train speed.

270. For any ordinary differences of radii the reduction of speed necessary to eliminate the additional centrifugal force due to a shorter radius is not great. Much misapprehension in this respect exists, owing to forgetfulness or ignorance of the fact that centrifugal force increases only as the degree of curvature, but as the square of the speed, so that comparatively trifling decrease of speed will place very material differences of radius on an equality in this respect. Thus, to obviate the effect of sharpening a curve from a 5° to a 10° we do not need to halve the speed, but only to reduce it in the proportion of $1 : \sqrt{2}$, so that if a speed of 60 miles per hour be safe on a 5° curve a speed of 42.43 miles per hour $\left(\frac{60}{\sqrt{2}}\right)$ is equally safe on a 10° curve; and if we again double the degree of the curve to 20°, we only reduce the admissible speed of equal safety by 12.43 miles per hour, or to 30 miles per hour.

This statement neglects the fact that the same excess of centrifugal force is more dangerous on a sharp curve than on an easy one; but the difference in that respect, while it exists, is small, because the lateral flange pressure is (contrary to a common misapprehension) unaffected by the degree of curvature.

271. The precise effect of curvature on the admissible speed may be determined as follows:

The centrifugal force C of any body of weight W moving at v ft. per second in a circle of r ft. radius is, in the latitude of New York,

$$C = \frac{Wv^2}{32.16r} \text{ (log 32.16, 1.50731)}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

To determine the centrifugal force of a body moving at V miles per hour on a $D°$ curve, we have $v = \frac{5280\,V}{60 \times 60} = 1.467\,V$, and $r = \frac{5730}{D}$. Substituting these values, we obtain

$$C = .00001167 \text{ (log 5.06722) } V^2D \times W. \quad . \quad . \quad (2)$$

Or, for the centrifugal force in lbs. per ton, multiplying the second member of the above equation by 2000, we obtain

$$C = .023348\, V^2 D \text{ (log } 8.36825). \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From this formula Table 106 is calculated, giving the centrifugal force in lbs. per ton of 2000 lbs. on any curve at any speed.

TABLE 106.

CENTRIFUGAL FORCE IN POUNDS PER TON OF 2000 LBS. ON VARIOUS CURVES AT VARIOUS SPEEDS.

[Computed by Eq. (3), par. 271.]

Speed Miles Per Hour.	Degree of Curve.				
	1°	5°	10°	15°	20°
10	2.33	11.67	23.35	35.02	46.70
20	9.34	46.70	93.39	140.09	186.78
30	21.01	105.07	210.13	315.20	420.26
40	37.36	186.78	373.57	560.35	747.14
50	58.37	291.85	583.70	875.55	1,167.40
60	84.05	420.26	840.53	1,260.79	1,681.06
70	114.40	572.03	1,144.05	1,706.08	2,288.10
80	149.43	747.14	1,494.27	2,241.41	2,988.54
90	189.12	945.59	1,891.19	2,836.78	3,782.38
100	233.48	1,167.40	2,334.80	3,502.20	4,669.60

The centrifugal force on any other curve is directly as the degree of curvature.

The heavy division lines mark the assumed maximum limit of speed for safety;—when the centrifugal force is ¼ W.

272. For the train to be overturned it is essential that the resultant of the centrifugal force and gravity shall fall without the base, which is upon the point of occurring, on a level track, as will be clear from Figs. 18 and 19, when

$$\frac{W}{C} = \frac{\text{cent. grav. above track}}{\text{half-gauge}}.$$

The height of the centre of gravity varies in different cars and locomotives from as little as $4\frac{1}{2}$ to 5 ft., in heavily loaded flat cars, to as much as 7 ft. in some types of locomotives. Assuming it at 6 ft., as in Fig. 18, makes some allowance for the beneficial effect of superelevation; which moreover, in the extreme case of danger of overturning, does not have its full effect, because, long before the point where it is imminent, centrifugal force will so act upon the springs as to throw the centre of gravity into nearly the position it would occupy if the cars were a rigid body and there were no superelevation.

FIG. 18. FIG. 19.

The maximum superelevation is about one seventh the gauge, or about eight inches. This may be considered as reducing the centrifugal force by one seventh of the weight of the body, or 286 lbs. per ton, barring the action of the springs.

273. We have, then, assuming the centre of gravity to be 6 ft. above the rails, and half the gauge (between centres of rails) to be 2.4 + ft.,

$$\frac{W}{C} = \frac{6.0}{2.4}; \quad \dots \dots \dots \quad (4)$$

whence $C = 0.4\,W$ when the train is upon the point of overturning.

But [eq. (2)] we have also

$$C = .00001167\,V^2DW, \quad \dots \dots \dots \quad (2)$$

and from eqs. (2) and (4) we readily obtain

$$V = \sqrt{\frac{0.4}{.00001167D}} = \frac{185.1}{\sqrt{D}}; \quad \dots \dots \quad (5)$$

this being the equation of the maximum velocity in miles per hour which a train can have without leaving the rails by overturning.

274. Long before this comes the point of danger, and long before that

again comes the point of more or less serious impacts, oscillation, and apprehension of danger. The minimum limit of objectionable speed, below which there may be said to be not only no sensible danger, but no possibility of annoyance or apprehension of danger, does not from its nature admit of exact determination; but we shall obtain a result corresponding closely with what have in fact proved wholly unobjectionable velocities on various curves if we assume this minimum limit to be when the action of the centrifugal force upon the car-body does not more than suffice, on easy curves having the usual (but, as we shall shortly see, probably too small) superelevation of about $\frac{1}{2}$ in. per degree, to throw it over so as to maintain it level despite the superelevation. The point at which this occurs may be determined as follows:

The springs of an easy-riding passenger car have been compressed through perhaps 6 in. by the weight of the car-body from their unloaded dimensions. An addition of $\frac{1}{12}$ of the weight resting on a spring, consequently, will compress it through an additional $\frac{1}{2}$ in., and an addition of $\frac{1}{24}$ of the weight resting on it will compress it through $\frac{1}{4}$ in. The shifting of this much of the weight to the outer springs involves a corresponding decrease of the compression in the inner springs; so that, assuming the leverage of the centre of gravity *of the car-body only* to be equal to that of the resisting moment of the springs, as it approximately is (see Fig. 18), a centrifugal force of $\frac{1}{24}$, or say $0.04 W$, will suffice to preserve the car-body level. Substituting this coefficient, 0.04 for 0.4 in eq. (5), we obtain

$$V = \sqrt{\frac{0.04}{.00001167D}} = \frac{58.536}{\sqrt{D}}; \quad \ldots \ldots \quad (6)$$

this being the equation of the inferior limit of the dangerous velocities; i.e., that at which the car-body of the easiest-riding coaches will at the most remain level, and not have a cant toward the outside of the rail, with the smallest usual superelevation.

275. As both the possible compression of the springs and the amount of superelevation soon reach a maximum limit, this particular criterion for determining what is the inferior limit of obnoxious velocities does not hold precisely and theoretically true when extended to the sharper curves, since it would require, for instance, on a 20° curve, 10 in. of superelevation and 5 in. compression of the springs, neither of which are admissible; but it has, nevertheless, the advantage before mentioned (par. 274) of corresponding tolerably closely with what have in fact proved wholly unobjectionable velocities on such curves, as it plainly should if cor-

rect for the lower curves. This appears in the tabulation of eqs. (5) and (6) given in Table 107, for curves of different radii up to a 60° curve (95 ft. radius), the latter being somewhat easier than the curve of 90 feet radius on the New York elevated railways, and hence to be regarded as about the maximum. The trains pass around these curves at 6 to 10 miles per hour without any disagreeable centrifugal force.

(See also par. 865 *et seq.*)

TABLE 107.

GIVING FOR VARIOUS CURVES THE INFERIOR AND SUPERIOR LIMITS OF SPEED WITHIN WHICH THE CENTRIFUGAL FORCE IS MORE OR LESS OBJECTIONABLE AND DANGEROUS.

[Computed by Eqs. (5) and (6), par. 273.]

CURVE.		MAXIMUM AND MINIMUM LIMITS OF SPEED. MILES PER HOUR.	
Degree.	Radius. Feet.	Minimum. Having no Disagreeable Effect.	Maximum. On the Point of Overturning the Vehicles.
2°	2,865	41.39 Miles per hour.	130.89 Miles per hour.
4°	1,433	29.27 " "	92.55 " "
6°	955	23.90 " "	75.57 " "
8°	717	20.70 " "	65.44 " "
10°	**573**	**18.51** Miles per hour.	**58.54** Miles per hour.
12°	478	16.90 Miles per hour.	53.43 Miles per hour.
14°	410	15.64 " "	49.47 " "
16°	358	14.63 " "	46.28 " "
18°	319	13.78 " "	43.58 " "
20°	**286**	**13.09** Miles per hour.	**41.39** Miles per hour.
22°	261	12.48 Miles per hour.	39.46 Miles per hour.
24°	239	11.95 " "	37.78 " "
26°	221	11.61 " "	36.72 " "
28°	205	11.06 " "	34.98 " "
30°	**191**	**10.69** Miles per hour.	**33.80** Miles per hour.
40°	143.3	9.25 Miles per hour.	29.27 Miles per hour.
50°	114.6	8.28 " "	26.18 " "
60°	**95.5**	**7.56** Miles per hour.	**23.90** Miles per hour.

The speeds in the last two columns are all *speeds of equal safety*, those in the last column being equal to those in the preceding column × $\sqrt{10}$ or 3.16. Multiplying or dividing either column by 2, 3, or any other factor whatever, will give a new column of speeds of equal safety.

276. These maximum and minimum limits correspond to a difference in centrifugal force of 1 to 10; yet it will be seen that the resulting velocities differ only as 1 to $\sqrt{10}$ or 1 to 3.16, as they should. It will also be seen that the permissible speed, by whatever standard, does not vary directly as the radius or inversely as the degree, as may be over-hastily assumed, but as the square-root of the radius or degree. That is to say, on any three curves having radii as

1, 2, 3,

the centrifugal force at any given velocity, it is true, is as

3, 2, 1;

but the coefficient of safety against overturning or of disagreeable or obnoxious effect of any kind admissible under any circumstances on a road operated by steam, is as

$\sqrt{3}$, $\sqrt{2}$, $\sqrt{1}$,

or as 1.73, 1.41, 1.00.

277. We may also note that the maximum necessary loss of time from a dead stop, in passenger service, under any ordinary circumstances, is only about three minutes, and the loss of time from slowing up for a quarter of a mile or so, under the quick command of the train given by the air, is very much less than this, while the steel rail has materially reduced the difficulty in and objection to making up for such delays by higher speed at other points. This is shown more fully in Chap. XIX.

For freight service alternations of speed by the use of brakes are still very objectionable, and perhaps will long continue to be; but ordinary curvature does not require this.

278. We may, therefore, conclude (in part on the authority of the matter referred to above, which it seemed more appropriate to postpone to Chap. XIX.) that any difference within the power of the engineer to effect is not likely to materially affect the ability to make ordinary express-train time. If it were a question between 2° curves or 20°, or between no curvature and a great deal, it might well make a serious difference; but under ordinary circumstances the question is rather between say, 6° and 10° curves, or between, say, 10 per cent more and 10

per cent less curvature. In such cases, on other than trunk lines running fast expresses, the importance of this particular question is not simply diminished *pro rata*, but entirely vanishes.

279. THE EFFECT OF CURVATURE ON THE SMOOTH RIDING OF CARS is a matter of more serious moment in not a few cases of lines with a large through-passenger traffic.

For day travel it matters less; but there is no doubt that since the general introduction of sleeping-cars not a little travel has been kept off the New York, Lake Erie & Western Railroad, for example, as well as other crooked railways, for this reason alone, when a straighter competing line existed. On the other hand, the number of lines to which, on account of the competition of other and straighter lines, this is an important consideration is not very great; and even when it is or may be, this also is peculiarly one of those cases in which, although a perfect cure would be exceedingly important and valuable, the partial cure from the slight modifications which are alone within the power of the engineer, without very great expenditure, will in most cases have little value. It is also to be remembered that if a curve is in thoroughly good shape the motion of a car is, after it has once entered the curve, almost as steady as on a tangent. If the centrifugal force and superelevation could be exactly balanced, the body of a traveller either in a sleeping-car or day-coach would be unaffected by either. Unfortunately this is out of the question; but the worst effect usually comes from entering and leaving a curve, and this again chiefly results from the fact that, as roads are ordinarily located, the line instantly changes from a tangent to a sharp curve. The consequence is, inevitably, a disagreeable lurch and "thud;" which would be much worse than it is except that the trackman with his bar corrects the errors of the engineer with his transit by "easing off" the curve at the ends, extending it a hundred feet or more on to the tangent, but of course necessarily sharpening the curve not a little for a short distance beyond the technical "P. C." The latter is unfortunate; but it is far better than to leave the curve as the en-

gineer stakes it out, and it never is so left on old and good track, so far as the writer has observed, but invariably flattened off at the ends by the trackmen.

280. The "easing off" should, it need hardly be said, be rather done by the engineer in proper form in the first place, in such manner as to avoid also the lesser evil of a kink in the body of the curve. A simple and practical method for putting in such transition curves involving hardly any extra work for this purpose (in fact rather facilitating the field work) is given in the field-book which succeeds this volume. See also close of Chap. XXX.

281. It may be added that, as more fully pointed out in the field-book referred to, the use of the parabolas instead of circular curves for railways, proposed in the early days of railway construction and in a few cases used, would have no important effect in reducing the evil described. What is wanted is (1), to ease off the curve by a rapidly changing radius for a short distance at the ends—a TRANSITION curve; and (2), to leave the great body of the curve of uniform radius. This the parabola does not accomplish.

282. THE MORAL EFFECT OF EXCESSIVE CURVATURE TO DETER TRAVEL—or rather, the moral effect of known excellence in that as in every other detail to encourage travel, is in not a few cases, —as for instance the Pennsylvania Railroad—a consideration of more importance than appears. Advertising is generally regarded by all business men as a profitable outlay, even when it is all outlay. When the advertising is of such a nature as to in part pay for itself by saving expenses, even if only to a limited extent, it becomes of course still more desirable, and in the case of railways has the peculiar advantage noted in Chap. III., that any additional sales they may thus make cost almost literally nothing.

In the case of some few roads which have an immense, an almost unlimited, traffic to contend for, this consideration alone may become of such great importance as to justify very heavy expenditure. Thus, the policy which the Pennsylvania Railroad has adopted of polishing and perfecting their line in this and in various other almost fanciful ways will doubtless prove a money-making operation, and largely on this account; for even with their great traffic, which will justify almost any expenditure to effect a perceptible improvement, it might perhaps be difficult

to justify the expenditures which they have made to take out some of their curvature by any correct estimate of the direct saving in operating expenses. One of the "almost fanciful" expenditures referred to is to secure absolute perfection of appearance, as well as real excellence, in the track and right of way by dressing the edges of the slopes of the broken stone ballast to an exact line, stone by stone, and by elaborately neat and tasteful road crossings. Another, and the one more particularly referred to, is the expenditure of occasional large sums in bold lines to eliminate curvature and trifling amounts of distance.

283. Between Harrisburg and Philadelphia the line of the Pennsylvania Railroad is one of the most instructive practical lessons on the subject of curvature, perhaps, which exists in the world. The old and very crooked line built by the State nearly fifty years ago is crossed almost every half-mile for long stretches by the newer line, which has been constructed piece by piece, and which has hardly one tenth the curvature, while at no point more than a few hundred feet from the old line. Comparison of the two is instructive in three ways:

First, and chiefly, the old line is an example of how immense amounts of curvature may be introduced merely from ignorance, carelessness, or inexperience, without the slightest real necessity. At very many points the new line was no more expensive than the old, while materially better.

Secondly, it is at many points an example of judicious construction, both on the new line and the old: the old line being very cheap, and answering a very good purpose while capital was scarce and traffic light, and involving little loss to throw away when these conditions had changed so as to justify the new line. Thus, while it was wise to throw away the work in the end, it was also wise to build it in the beginning.

Thirdly, there are various points where the new line, however more pleasing to the eye, may be seen to be far more expensive than any ordinary traffic would justify in proportion to the end attained. The Pennsylvania Railroad, however, has not an ordinary traffic.

284. But, after all, the lines are few which have so large a competitive traffic to lose or gain as to make the advertising value of a better line a consideration of much moment, and then it only becomes such when it is only one form of a general and notorious policy. With the Pennsylvania it is so. Its track is well known among well-informed railroad men, the world over, to be distinctly superior in its finish, if not in its real excellence, to

anything which exists in any part of the world, and the same spirit pervades most of the details of its management, but only when the competition is very close, the traffic very heavy, and the amount of avoidable sharp curvature in question very large, could it do so. In a new and direct trunk line between Philadelphia or Chicago and New York, for example, it would be a very important consideration.

285. So far, the miscellaneous and indeterminate objections to curvature discussed apply chiefly to passenger travel. Another of great importance applies only to freight traffic, viz.: THE EFFECT OF CURVATURE, and especially sharp curvature, AS AN OBSTACLE TO THE USE OF HEAVY AND POWERFUL TYPES OF LOCOMOTIVES. Without attempting to summarize now the mechanical reasons for the conclusion, which are given later (Chap. XI.), it is a fact that, in spite of occasional obstinate opposition to certain types of engines being used "on our curves" by men who ought to be good judges, there is not the slighest evidence to show that all the types now in use are not mechanically very nearly on a par as respects the physical possibility of being advantageously operated over any ordinary and reasonable curvature. The wear and tear is a little greater with heavy engines, as we shall see; but that is not now the question before us.

Certainly up to the limit of 10° curves (573 feet radius) this objection is wholly unfounded. The New York, Lake Erie & Western, Baltimore & Ohio, and numerous other lines (see Table 116) have curves of that radius exposed to the heaviest and fastest traffic, over which Consolidation engines run without the slightest evidence of peculiar difficulty, danger, or wear and tear. In the coal regions of Pennsylvania 14° and 16° curves are not at all uncommon on branch lines, and for operating such lines the Consolidation engine was first designed and had its first success.

286. The Consolidation engine was designed by Mr. A. Mitchell, then Master Mechanic of the Lehigh Valley Railroad, in 1872. The type was so novel that the Baldwin Locomotive Works were reluctant to undertake its construction. The Atchison, Topeka & Santa Fé Railroad in

1881 operated 16° curves with a 60-ton Consolidation locomotive (see Trans. Am. Soc. C. E., 1880, Paper No. CLXXX), with the result that "it is believed that the Consolidation engine travels the 16° curves with as much ease as the ordinary 'American' engine, and causes less wear of track and permanent way."

287. In the "Seventh Annual Report of the American Railway Master Mechanics' Association" (1876, p. 13) a committee of five prominent master mechanics and mechanical engineers report as follows:

"With reference to the loads hauled by these heavy engines, it may be well to say that no practical difficulties are experienced on the Pennsylvania and Northern Central railroads' level divisions in hauling trains of 80 or 90 loaded cars at 15 miles per hour. These long trains are hauled around sharp curves, of which the radii range from 650 feet (8° 50') upward. In exceptional cases very much sharper curves are passed. Thus on the Baltimore & Ohio Railroad there is a Y with curves of 136 feet radius (42° curves), and Consolidation engines are run around these curves without trouble. In fact no difficulty has been reported in using them in all cases like ordinary freight engines."

288. In the same report (p. 123) we have a report of experiments at Renovo, on the Philadelphia & Erie Railroad, to determine the relative

TABLE 108.

COMPARATIVE RESISTANCE ON CURVES OF VARIOUS TYPES OF LOCOMOTIVES.

According to experiments on the Philadelphia & Erie Railroad.

[The precise results of this table *cannot be accepted as accurate*, but they are of value as indicating that there is at least no great difference against the heavier types.]

Kind of Engine.	Weight.				Diam. of Drivers.
	Drivers.	Truck.	Tender.	Total.	
	lbs.	lbs.	lbs.	lbs.	ins.
American	48,000	20,500	32,600	101,100	60
Ten-wheel	52,800	22,600	47,700	123,100	55
Consolidation	78,500	9,700	47,700	135,900	49

Kind of Engine.	Length of Wheel-base.		Resistance on 4° Curve at 10 Miles per Hour.		
	Rigid.	Total.	Total.	Lbs. Per Ton	Lbs. P'r Deg.
	ft. in.	ft. in.	lbs.	lbs.	lbs.
American	7 6	21 10½	1,963	39	9.75
Ten-wheel	12 5	23 8	1,750	28.4	7.1
Consolidation	14 6¼	21 1	1,850	20.0	5.0

curve resistance of various engines, which indicate, so far as they go, that if we may estimate relative adaptability to and danger on various curves by the relative resistance, the heaviest class of engines are at least as well adapted to, and as safe on, sharp curves as any other class of engines. Table 108 gives a summary of these experiments, which were made by Mr. Isaäc Dripps, General Master Mechanic of the Philadelphia & Erie Railroad, with a recording dynamometer car which he guarantees to have been correct; but notwithstanding this guarantee, it seems almost certain that there must have been some defect of apparatus which partially vitiates the results, as they seem unduly favorable to the Consolidation type. The tests may be accepted, however, as indicating quite strongly that the difference is not great against them. The speed was kept as near 10 miles per hour as possible, and the effect of varying velocity estimated from the diagram.

289. Mr. Dripps says:

"The locomotives were in good working order, and were generally taken for the experiments as soon as detached from their trains, the only preparation necessary being to disconnect the piston-rods from the cross-heads so as not to have the friction of the piston in the cylinders. All the other connections were left precisely as if running by steam, so that the friction due to all the working parts of the locomotive, except the friction of the piston within the cylinders, would be indicated. The locomotives experimented with were pulled by another locomotive and the dynamometer car. They would have been pushed except for the danger of snow blowing on the track.

"These experiments prove conclusively, that heavy locomotives properly designed, with a short-wheel base, and with as many bearing points on the rails within such base as possible,—thus reducing the weight on each bearing point,—will pass around curves with less friction, and be less destructive to the track, than the ordinary passenger locomotive of much less weight. Of course these heavy locomotives are best adapted for slow speeds, and will show the greatest economy, and will work to the best advantage on railroads having double track, heavy grades, and a heavy freight traffic.

"The effective power of Consolidation locomotives is 50 per cent more than the ordinary six-wheel connected freight locomotive; and from actual service I find that the locomotives of this class work up to their power fully as well as, in fact better than, the six-wheel connected locomotive. Two locomotives of the Consolidation class will do the same work—haul as many cars—as three of the six-wheel connected class; and as three of the latter will cost $10,000 more than two of the former, there is thus a saving of $10,000 in the original outlay, and the saving of wages of the crew of one locomotive (and train) daily; and with a properly constructed locomotive of the Consolidation class the running repairs for tonnage hauled will be less than any other class of locomotives now in

use. On the narrow-gauge Denver & Rio Grande Railway, which has many 24° and 30° curves, the Consolidation type is almost exclusively used for freight service, the wheel-base being only a little shorter than is usual for standard gauge, or in the proportion of about 12 to 15 feet."

290. The preceding facts, taken altogether, seem conclusive that objections to the use of any reasonable amount or radius of curvature whatsoever, on the ground that it will be peculiarly objectionable for the heavier types of locomotives, finds but little warrant in fact. Indeed, it is noticeable that it is on roads of much and heavy curvature that the Consolidation type has been most readily adopted and is most in use.

291. We have now discussed all the indeterminate and imaginative (but not therefore imaginary) objections to curvature, and found that while all of them have a foundation in fact, and may be at times of great importance, yet that on the contrary some of them are always, and all of them are sometimes, of so little moment that for the most part they should have no appreciable effect on the decision as to what curvature to use. We will therefore return to the concrete and definite objections to curvature, viz., its direct effect upon operating expenses and on length of trains (the latter considered in Chaps. XVIII. and XIX.). In order to discuss these intelligently we must first consider the abstract question of the mechanical laws of curve resistance, from mistaken notions as to which much that is mistaken may arise in practice.

THE MECHANICS OF CURVE RESISTANCE.

292. Curve resistance has never yet been exhaustively investigated, and our knowledge is in several respects deficient. The more essential facts are now tolerably well determined; but simple as the subject appears, the mechanics of a rolling truck on a curve is—to determine it correctly—a very intricate problem, the solution of which we must attempt to make clear.

293. The forces arising from the fact of curvature are of three classes:

1. *Forces originating in and confined in their action to the truck itself*, causing the slippage of the wheel on the rail which is the ultimate source

of all curve resistance. The following two classes of forces can only act by augmenting or diminishing the former:

2. *Centrifugal and centripetal force:* acting upon the car as a whole, and communicated to the truck through the centre-pin and side-bearings.

3. *A force due to obliquity of traction* originating within the train as a whole and communicated to the car-body, and thence to the truck.

We will consider the nature and action of these forces in their order:

294. The position assumed by any rectangular flanged wheel-base in passing around a curve is shown by observation and experiment to be that shown in Fig. 20.* The front outer wheel crowds hard against the rail, and the rear axle then assumes a radial position, neither flange touching the rail unless the gauge is so tight or the wheel-base so long as to bring the inner rail up to the flange rather than the flange to the rail. Fig. 20 shows the position of STABLE EQUILIBRIUM to which, if any force disturb the position of the wheels for a moment, they promptly return. Therefore, if any force is to permanently change their position it must be sufficient to slide them laterally on the track. Otherwise it will not produce motion at all. To slide the wheels, as to lift a weight, the $\frac{1}{1000}$ of an inch requires as great a static force in pounds as to slide it a foot or a mile. The POWER CONSUMED varies with the distance moved, but the force required to produce motion at all does not vary.

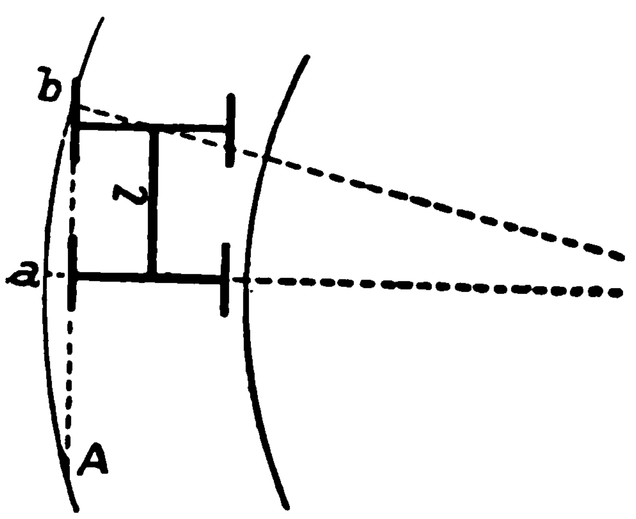


FIG. 20.

This position is likewise shown by experiment to be assumed just the same, however great or little the superelevation. This fact may be observed by watching the motion of cars around the first sharp curve in any yard.

295. The writer constructed some heavy models with both cylindrical and sharply coned wheels, the wheel-base being capable of increase or decrease at pleasure, and the gauge and radius being likewise adjustable by moving the rails. The flanges, however, were made almost vertical, and with a sharp interior fillet, in order to give an exact point to measure from. He found that coning did not

* The writer believes he was the first to observe this fact, and determine it experimentally. The general fact that the rear flanges stand away from both rails he has since found had been previously observed by a number of individuals, but even that is not generally known to this day.

exercise the slightest influence on the position assumed by the wheel-base, which was invariably that stated, the front outer wheel being always in contact with the rail at *b*, Figs. 20 to 23, and the rear outer wheel standing away from the rail by a distance *a*, which, so far as the writer could determine it, was always precisely equal to the *versed sine of a chord of twice the length of the wheel base* (see Fig. 20), indicating that the rear axle was always radial. In only one case did this fail,—in that outlined in Figs. 21 to 23,—and then only because it was impossible for the wheels to assume it. If the gauge was so tight, the wheel-base so long, or the curve so sharp (or any two or three of these together) that the distance *a* by which the rear wheels naturally tended to stand away from the outside rail was greater than the play of the gauge, then the rear axle simply moved over until it pressed against the inner rail, as shown in Fig. 22.

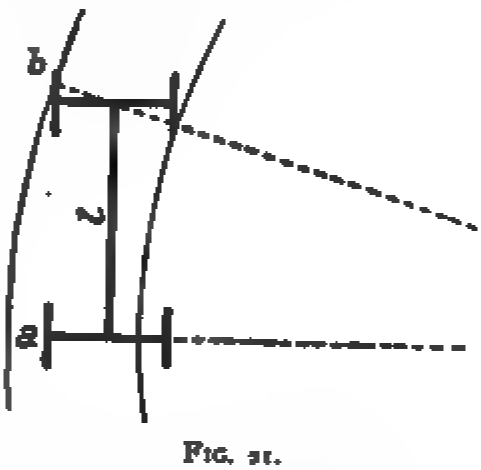


FIG. 21.

296. With European rolling-stock, having no truck, this condition usually prevails, so that their rails wear quite differently on curves from ours, both inner and outer rail being ground by the flange. On this account it is frequently laid down in European text-books that the position outlined in Fig. 22 is the normal one for any wheel-base in curves, but this error arises from insufficient investigation, and is disproved by American experience as well as experiment.

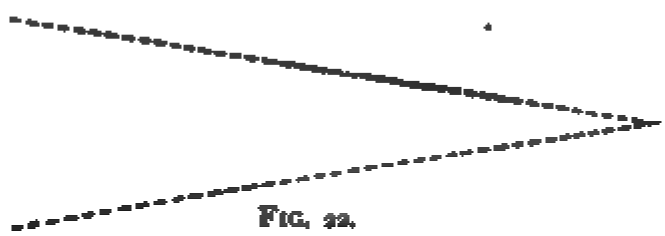


FIG. 22.

When the inner rail was entirely removed, so that the inner wheels ran on their flanges, the position and path of the wheels was in no way affected, showing tha the inner rail performs no necessary function in guiding the trucks, but merely supports the wheels.

297. These facts disprove the old hypothesis that coning would enable the wheels to adapt themselves to the unequal length of inner and outer rail, and maintain a radial position. They can only do so when the axles individually are free to assume a radial position. Moreover, owing partly to this fact, and partly to the effect of the ordinary wear on tan-

gents, the tread wears down near the flange very rapidly; and such coning as there may be soon disappears. We may therefore neglect it hereafter, and assume the wheels to be cylindrical. The coning now put in wheels is chiefly useful as a prospective provision for wear; and experiment shows that whether the wheels be coned or not, the tendency of any rectangular wheel-base is to roll very nearly in a straight line.

298. As we have seen that the rear axle is always radial to the curve, the front axle, Figs. 20 to 23, stands at an angle A, Fig. 23, to the rail, equal to the arc subtended by the length of the wheel-base, l. With a 5-ft. wheel-base (the usual length for freight trucks) this angle would be, on a 1° curve, .05° or 3′, and proportionately on other curves; with a 12-ft. wheel-base the angle is 0.12° = 7.2′. The distance by which the rear outer wheel, Figs. 20 to 23, stands at a distance from the outer rail (being equal to the versed sine of the arc subtended by l) is readily determined to be, from what has preceded,

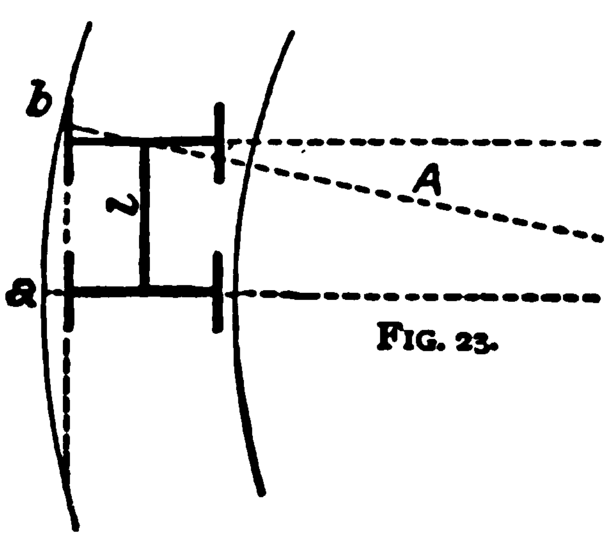


FIG. 23.

For a 5-ft. wheel-base, .0022 foot per degree of curvature.
For a 12-ft. wheel-base, 0.0127 foot per degree of curvature.

299. The gauge of a road is the exact distance between inside of rails and the gauge of the wheels is usually set so as to allow a normal play of from $\frac{3}{8}$ to $\frac{5}{8}$ inch, averaging about $\frac{1}{2}$ inch or .04 feet. The rear inner wheel, then, of a 5-ft. wheel-base will be close against the inner rail on a $\frac{.04}{.0022} = 17°$ curve +, and a 12-ft. wheel-base on a $\frac{.04}{.0127} = 3°$ curve +. In watching ordinary cars pass around a curve, however, there will be considerable fluctuations in the position of the rail owing to irregularities of both curve and truck.

300. The slipping of wheel on rail on a curve arises from two causes: First. *Longitudinal slipping*, due to the difference in length of inner and outer rail. This difference on any given curve, or part of a curve, is equal to an arc of a radius equal to the gauge, and the same number of degrees long; i.e., it is, on any given distance d, $d \times \frac{g}{r}$, or, on a

1° curve and standard gauge, $d \times \frac{4.7}{5730} = .00082d$. On any other $D°$ curve it will be $0.00082dD$.

Secondly. *Lateral slipping*. The front wheel, as we have seen, stands at an angle A, Fig. 23 or a, Fig. 24, to the rail. In rolling through an

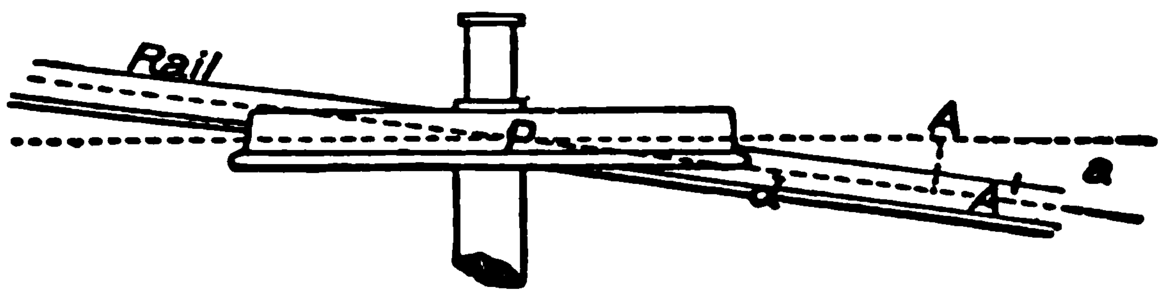


FIG. 24.

infinitesimal distance d, therefore, the wheel, since it tends of itself to roll straight forward in the direction PA must be slidden laterally through a distance $AA' = d \sin a$.

For a 5-ft. truck on a 1° curve.......... $AA' = d \sin 3' = .00087d$.
For a 12-ft. truck on a 1° curve.......... $AA' = d \sin 7.2' = .0021d$.

This lateral slipping takes place only on the front axle, since the rear axle, as we have seen, is and maintains itself radial to the curve.

301. On the front axle both lateral and longitudinal slipping is taking place simultaneously and continuously, and the question then arises how the longitudinal slipping is divided—whether the outer wheel slips forward or the rear wheel backward, or the total amount is divided between the two. A single experiment as to this point, as careful as its delicate nature would permit with ordinary rolling-stock, was once made on the "Horse-shoe curve" of the Pennsylvania Railroad, with the conclusion that both wheels slipped; but it is impossible that this condition obtains generally and continuously, since that wheel will slip which can slip easiest, and the slightest variation in either the load or the coefficient of friction will give one wheel or the other an advantage in this respect. Either the superelevation or the centrifugal force is alone competent to produce enough inequality of load to effect this, for one or the other must always be in excess, unless by accident. And furthermore, if one wheel should begin to slip first, it would certainly continue to do so, for the same reason that when a locomotive driver begins to slip, its ratio of

adhesion (i.e., coefficient of friction) is heavily reduced. It may therefore be considered as certain that all longitudinal slip in every case, unless by accident, is confined to either the inner or outer wheel exclusively; although it may not be the same wheel for any two successive axles, nor for any two consecutive moments.

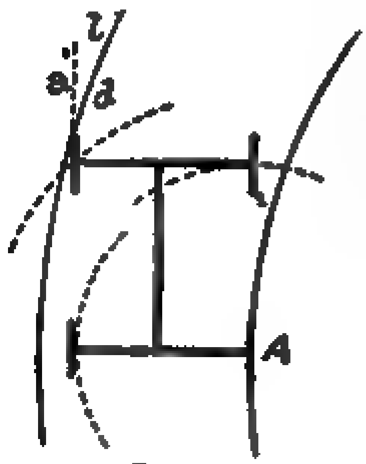


FIG. 25.

302. Admitting this to be true, the truck in rolling on a curve is rotating about some one wheel, A, as a centre, as shown in Fig. 25; and we have the following condition of things in, say, a 5-foot truck rolling around a curve:

(1) One rear wheel, A, is not slipping at all in either direction.

(2) One rear wheel is slipping longitudinally at the rate of $.00082dD$ (in a 12-ft. truck also, $.00082dD$).

(3) One front wheel is slipping laterally at the rate of $.00087dD$ (12-ft. truck, $.0021dD$).

(4) One front wheel is slipping both laterally and longitudinally at the same rates as in the above, giving a combined rate of

$$\sqrt{.00082^2 + .00087^2}\; dD.$$

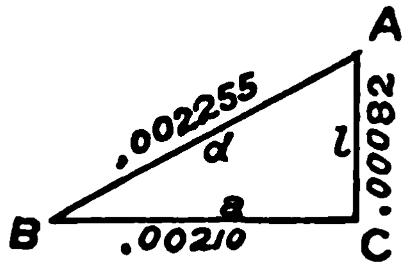
Table 109 gives the summary of the slipping thus indicated.

TABLE 109.

TOTAL SLIPPING OF ONE WHEEL IN FEET THAT TAKES PLACE IN PASSING OVER 100 FT. OF VARIOUS CURVES.

303. The formula (4) requires explanation: Since the wheel is slipping in two directions at right angles to each other, it will at each instant

of time, while advancing over an infinitesimal distance, *d*, Fig. 25, slip longitudinally in the direction *a*, and laterally in the direction *l*. The true direction and amount of slipping will therefore be—neither *a*, nor *l*, nor both together—but along the diagonal *d*. Figs. 26 and 27 represent to scale the actual conditions.



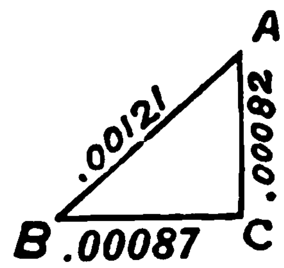


FIG. 26.—12-FT. TRUCK. FIG. 27.—5-FT. TRUCK.

Amount and constituent elements of the slip of the wheel *A*, Fig. 25, in passing over a distance *l* on a 1° curve.

This is merely following the fundamental law of the composition of velocities, which is the same in its nature as the composition of forces. It has been carelessly assumed at times that a total sliding of the wheels represented by the sum of the two sides *a* and *l* rather than by the hypothenuse *d*, measures the distance through which the wheel slides, and the consequent loss of foot-pounds of energy, but this is palpably erroneous.

304. It will be observed that according to Table 109 the wear due to curvature on the front wheels is more than double (4.16 to 1.64) that on the back axles. Any check upon this from observed wear of car wheels is in the nature of things impossible from the fact that the direction of motion of the car is reversed with every trip. With engine and tender trucks, however, this is not the case. Statistics of this kind likewise are very difficult to obtain; and the following little table (Table 110), embracing observations on the Camden & Atlantic Railroad, is all of the kind which the author has ever been able to discover. This, however, appears as far as it goes to strikingly confirm the theory advanced. It is to be observed that the wear of tender-truck wheels is 11.2 per cent greater on the front than on the back axle, and the wear of the engine truck-wheels 37.6 per cent greater. In considering these figures it is to be remembered:

1. The Camden & Atlantic has very little curvature.
2. Curvature is only one cause for wheel wear, the others being use of brakes and sand, original defects and regular running wear on tangents, which would be, if not substantially equal for both axles, much more nearly equal than that from curvature.

The average might be and probably is somewhat affected by a tendency—especially on a small road where the engines were well known—to condemn two wheels at once which had been running the same time, although there might really be not a little difference in their wear. The great excess in the difference in wear in the engine trucks is notable.

TABLE 110.

WEAR OF LEADING AND TRAILING WHEELS OF LOCOMOTIVE AND TENDER TRUCKS ON THE CAMDEN & ATLANTIC RAILROAD.

[Compiled from Report to Am. Ry. M. M. Assoc. on Loc. Wheels and Axles (Rep. 1878, p. 23), by Rufus Hill, M. M.]

ENGINE TRUCKS.

Size.	No. of Pairs.	Mileage. Lead.	Mileage. Trail.	Relative Life of Wheels on Front Axle. Back Axle = 1.0.	Remarks.
28 in.	8 each.	28,998	43,024	.674	Av. all eng. wheels, 28,623.
26 "	"	15,461	27,008	.573	Av. all tender wheels, 26,821.
Average..........		22,230	35,016	.624	

TENDER TRUCKS.

Size.	No. of Pairs.	Lead.	Trail.	Relative Life	Remarks.
30 in.	10 each.	27,897	31,997	.87	Front truck.
"	"	29,249	32,736	.894	Back truck.
28 in.	"	23,419	23,560	.994	Front truck.
"	"	20,365	25,346	.803	Back truck.
		25,232	28,410	.888	

The table is stated to have been made up from records of condemned wheels only, so it does not give a fair idea of the average mileage of all wheels.

305. It does not follow that the total slippage, and hence total curve resistance, of a six-wheel truck would follow exactly the same law as that of a four-wheel truck of the same length of wheel-base and carrying the same load; but it is useless to consider that question for lack of positive knowledge as to the position naturally assumed by a six-wheel truck. It is probably the same as if the middle pair were omitted, but there is no evidence of that fact.

306. Although we have seen that coning, however much or little there may be, has no influence whatever in practice upon the position assumed by the truck, yet if any coning exists it will certainly modify the AMOUNT of slipping, and hence the resistance. To consider how much it will or may modify it, however, would lead us into hopeless and profitless intricacy, because there must be slippage under any circumstances with a rectangular wheel-base, which will speedily wear away the coning on the working part of the tread.

It is probable, however, that the effect of the coning while it exists is either *nil* or positively injurious, taking front and rear axle together, for the reason that the position assumed by the wheels bears no relation to that required by the coning and, especially on the front outer wheel, is liable to increase its diameter unduly.

307. So far, there is as little reason to doubt our correctness as can be expected in any subject which has not been exhaustively and thoroughly investigated experimentally; and frictional slippage which has been estimated includes all that takes place between rail and wheel except (1) that due to flange friction and (2) the possible action of other forces communicated to the truck.

308. To determine the resistance arising from the slippage estimated, the very delicate question arises of what is the coefficient of sliding friction under such circumstances.

The primary fact to be remembered in estimating this is that the velocity of the sliding surfaces on each other is very small, as shown more fully in the following Table 111, computed directly from the preceding Table 109, by assuming that 10 miles per hour = 15 (instead of 14.67) feet per second.

TABLE 111.

VELOCITY IN FEET PER SECOND WITH WHICH THE WHEEL SLIDES ON THE RAIL ON VARIOUS CURVES.

VELOCITY OF TRAIN.	VELOCITY OF SLIDING; FEET PER SECOND.							
	5-Foot Truck.				12-Foot Truck.			
	1°	5°	10°	20°	1°	5°	10°	20°
10 miles per hour..	.012 to .018	.06 to .09	.12 to .18	.24 to .36	.012 to .034	.06 to .17	.12 to .34	.24 to .68
30 miles per hour..	.036 to .054	.18 to .27	.36 to .54	.72 to 1.08	.036 to .102	.18 to .51	.36 to 1.02	.72 to 2.04

Our knowledge of the coefficient of sliding friction at these extremely low velocities may be summarized as follows:

1. It is materially greater than at ordinary and perceptible velocities,
2. It is very greatly more sensitive to minute changes of velocity than at ordinary and perceptible velocities.
3. Its maximum at a velocity of 0 + is something over ¼ with locomotives and perhaps ¼ with car wheels as ordinarily loaded.

These laws were most authoritatively determined and most completely illustrated by the famous brake experiments of Capt. Douglas Galton and Mr. George Westinghouse, the general results of which are embodied in Tables 112 and 113. We shall have occasion to refer to

TABLE 112.

COEFFICIENTS OF FRICTION BETWEEN CAST IRON BRAKE-SHOES AND STEEL-TIRED WHEELS.

[Determined by Experiments of Capt. Douglas Galton and Geo. Westinghouse, Jr. Trans. Inst. M. E., 1878.]

VELOCITY. MILES PER HOUR.	COEFFICIENTS OF FRICTION.				
	At First.	After 5 Sec.	After 10 Sec.	After 15 Sec.	After 20 Sec.
0 + to 1 or 2	.250	....	....	....	....
7½	.242	....	....	....	....
13½	.213	.193	....	....	....
17	.205	.157	....	.110	....
20½	.182	.152	.133	.116	.099
27	.171	.130	.119	.081	.072
30½	.163	.107	.099	....	....
34	.153	....	....	....	....
37½	.152	.096	.083	.069	....
41	.144	.093	....	....	....
48	.132	.080	.070	....	....
54	.106	....	....	.045	....
60	.072	.063	.058	....	....

While these results are unquestionably more nearly correct than any other existing evidence, there is considerable room for doubt as to the exact values given.

TABLE 113.

COEFFICIENTS OF FRICTION OF SKIDDED WHEELS.

[As determined in the Galton-Westinghouse Experiments. See Table 112.]

VELOCITY. MILES PER HOUR.	COEFFICIENT OF FRICTION.	
	Steel Tire on Steel Rail.	Steel Tire on Iron Rail.
0 +	.242	.247
7	.088	.095
13	.072	.073
27½	.070	... .
34	.065	.070
41	.057	....
52	.040	.060
54	.038	....
60	.027*	....

* Mean of three tests only.

these experiments frequently. Many independent experiments confirm their essential truth.

309. Assuming $\frac{1}{4}$ as the coefficient, the resistance of the wheels, if slid through all the distance that they are advanced along the track, would be in lbs. per ton,

$$2000 \times \tfrac{1}{4} = 500 \text{ lbs.}$$

As, however, on a 1° curve, they only slide through an average of .00073 of that distance, the resistance arising from surface friction only between rail and wheel would be $R = 2000 \times \frac{1}{4} \times .00073 = 0.365$ lb.

This is the curve resistance (except for error in the coefficient) that can be accounted for at slow velocities, excluding flange friction and the effect of shocks and irregularities. From the general laws of friction summarized above, it would seem probable that both the surface and flange friction would decrease with either (1) increase of velocity or (2) decrease of radius, which has the same effect to increase the velocity of sliding, at any given speed.

In Appendix A will be seen experimental evidence tending to support the first of these conclusions, and by inference the second also.

310. A third theoretical cause of surface friction has been suggested, viz.: Rotative friction of the wheel on the rail, due to the fact that it not only slides but revolves, but its existence cannot be conceded.

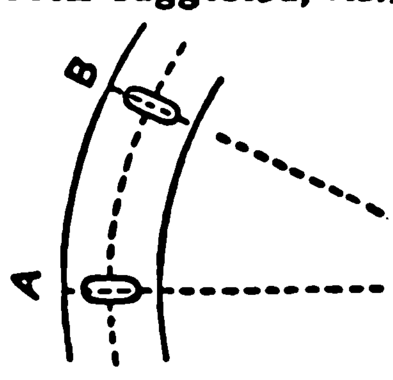


FIG. 28.

It is true, as claimed, that the actual contact is by a surface and not a theoretical point or line; but although the wheel, in moving through an infinitesimal distance AB, Fig. 28, is actually rotated, yet as this takes place simultaneously with the other sliding its effect is simply to decrease the velocity on one side of the center of contact by as much as it increases it on the other side.

311. FLANGE FRICTION.—We have seen that, at each instant of time, the truck rotates through a minute angle, turning as it were on one or the other of its rear wheels, A, Fig. 25, as a pivot; the other three wheels sliding on the surface of the rail in the direction indicated by the dotted lines. The force which causes this rotation—the only force which exists to do so—is the reaction or pressure of the rail against the flange of the front outer wheel.

It necessarily follows from this fact that, assuming that the coefficient of friction is not affected by the velocity of sliding, this pressure or reaction is always the same on curves. For, however easy the curve, a

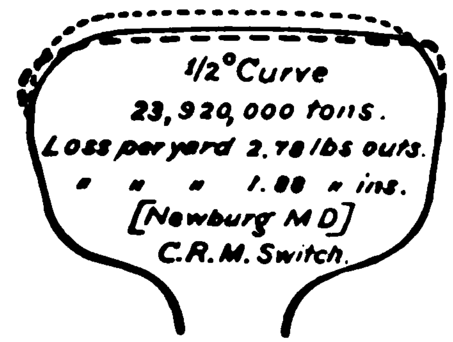


FIG. 32.

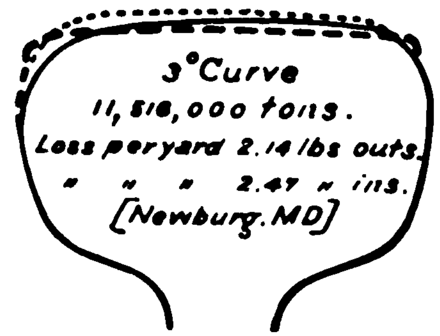


FIG. 33.

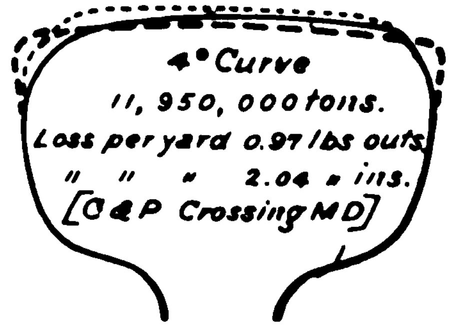


FIG. 34.

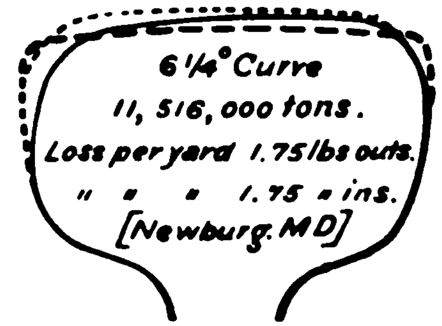


FIG. 35.

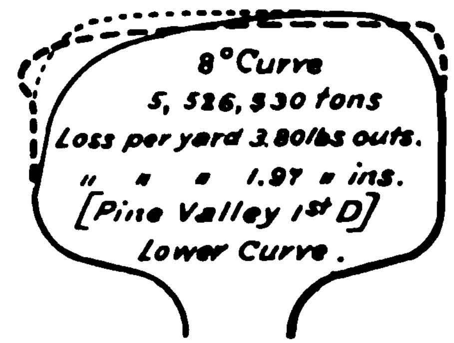


FIG. 36.

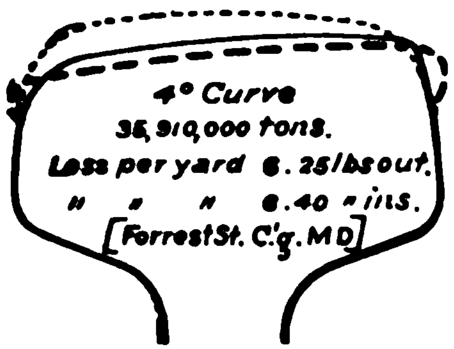


FIG. 37.

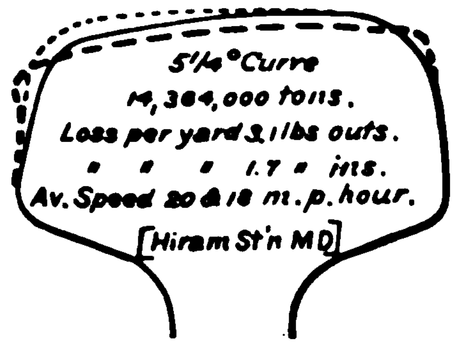


FIG. 38.

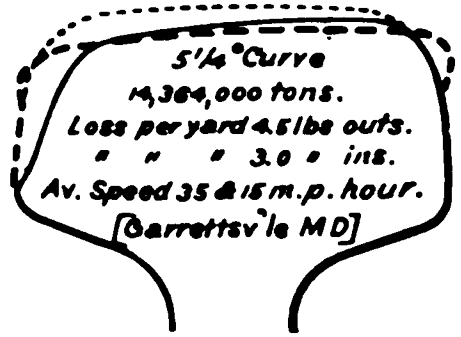


FIG. 39.

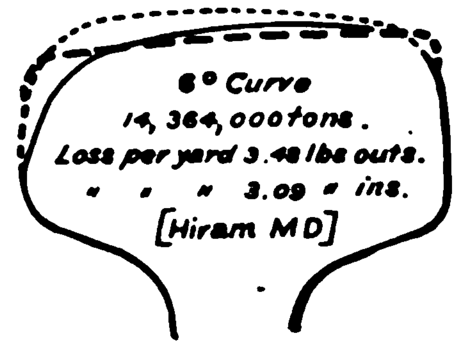


FIG. 40.

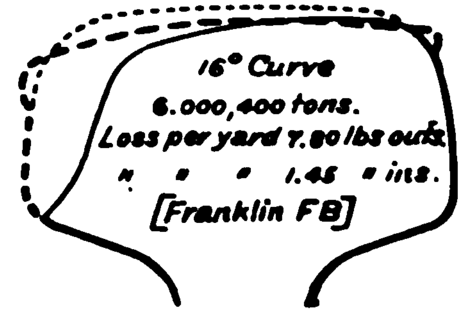


FIG. 41.

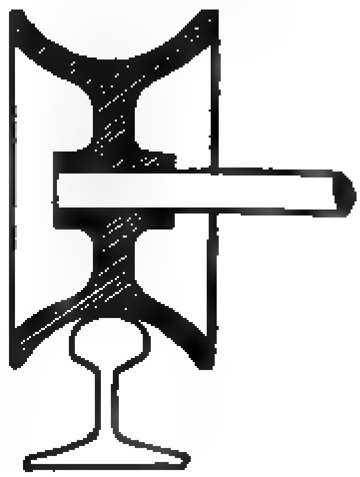
FIGS. 32–41.—DIAGRAMS ILLUSTRATING THE LAW OF RAIL WEAR ON CURVES.

The highest, lightly-dotted line shows the original section of the rail. The heavy-dotted line shows the section of the INSIDE rail, after sustaining the tonnage given for each. The solid line shows the corresponding section of the opposite OUTSIDE rail. It will be seen that the inside rail is distorted so as to widen the head, showing a wear and slipping dead on top, while the outside rail cuts away on the corner, and when the wear has proceeded far enough (as in Figs. 39 and 41) cuts it to almost the exact form of the flange, but with a sharper corner. The wear of the outside rail on the easier curves of 3° to 8° takes the same form in time and is then much more rapid, but in these particular specimens the wear has not continued long enough to reach this stage. See par. 315.

position of rail and wheel shown in Fig 31. Figs. 32 to 41 give a series of rail sections selected from a great number taken by the writer on the Atlantic & Great Western (now New York, Pennsylvania & Ohio) Railroad, showing the wear which actually results from the conditions watched. They were exact copies originally, to full scale, and are now reduced one half.

Fig. 30 is a half-scale section of a new flange and rail section of ordinary form (they vary somewhat in outline, but that is unimportant) in their natural relative position on a tangent. Fig. 31 shows the same new flange and rail section in their natural relative position ON ANY CURVE WHATEVER, however sharp or flat.

D



curve of any radius.) FIG. 31.

FIG. 42.

The tread stands entirely free of the top of the rail, the surfaces in contact being neither the horizontal tread nor the vertical flange, but the curved surfaces which are perpendicular to the resultant shown in Figs. 29 and 31. To understand this, let the reader turn Fig. 31 around diagonally until the diagonal stands in a vertical position, and let him conceive it to represent the vertical force of gravity alone. He will see that the wheel would naturally take this position—as naturally as a wheel shaped like Fig. 42 rolls on the central curved surface instead of the side surfaces.

314. The consequences of this condition of things are these:

First. The disproportion in the diameter of the wheels; hence the necessary longitudinal slipping, and hence the curve resistance, is materially increased. If the increase of radius of wheel be $\frac{1}{16}$ inch, the extra distance slipped through per station of 100 feet by one wheel will be 1.16

feet; which, by referring to Table 109 on page 286, will be seen to be as much as occurs on the surface of the rail on a 4° curve. This increase, it follows from what has preceded, is constant for all curves, and thus tends to disproportionately increase the resistance of easy curves. But precisely how much the resistance thus arising may be with new wheels, it is profitless to inquire, because,

Secondly, The inner angle of the wheel and the outer corner of the rail is gradually worn away, the greatest wear being always on the corner of the outside rail and in the direction of the resultant (see Figs. 32 to 41), on curves of all radii.

The rapidity of wear depends, not upon the pressure, which is constant on all curves, nor (to any marked extent) upon the angle of wheel to rail, but upon the amount of sliding which takes place—or, in other words, varies directly as the degree of curvature.

315. Finally, from the effect of these causes we have a still further change of conditions, viz.:

Thirdly. As the wear proceeds, the surfaces in contact become larger and larger, and this introduces a further source of slippage, rail wear and curve resistance, the ultimate form of which is shown in Fig. 41. That particular section was taken from a 16° curve; but the outer rail on all curves, of however long radius, tends to take precisely the same form in the end. Thus in some similar sections to those shown in Figs. 32 to 41, on the Pennsylvania Railroad, rails from 4° curves after sustaining nearly four times the tonnage of the rails shown in Fig. 34, were in even worse condition than the rail from a 16° curve shown in Fig. 41.

In a rail worn like Fig. 41, the true bearing surface on which the wheel rolls (compare Fig. 31) is directly on the corner, and the rubbing surfaces above and below are revolving in a circle of nearly ½-inch longer radius, the average of the whole surface being nearly if not quite ¼ inch.

It necessarily results from this, that while the wheel is rolling through any distance its surfaces slip on the rail through $\frac{16.5}{0.25}$ or $\frac{1}{66}$ of that distance; = 1.51 feet in 100.

316. The coefficient of friction, moreover (as well as rail wear), with such large surfaces in contact, is probably considerably larger than when the bearing is on a mere point, as in the unworn rail, Fig. 31; for the formerly accepted "law" that friction is independent of the areas in contact has been proven untrue for lubricated and still more for unlubricated surfaces, as was found out practically long since with brake-shoes.

The information on friction laid down in most of the standard text-books is very deceptive.

317. This third source of extra resistance, due to badly worn rails, is reached in a much shorter time on sharp curves, and as a rule exists only on them; but nevertheless, when it exists, the amount of the extra resistance caused thereby is *independent of the radius.* If rails be equally worn it will amount to substantially the same on all curves.

When the wear has become so great that the rail has the form of Fig. 41, so that the flange bears against the rail almost down to its point, the wear, and resistance as well, is doubtless very much increased. In a lot of rails which have been all exposed to substantially the same tonnage, like those in Figs. 32 to 41, this condition will be likely to exist only on the sharpest curves, and accordingly the apparent indications of a test of such rails will be that rail wear increases very much more rapidly than the degree of curvature—in fact nearly as the square of the degree of curvature.

The writer himself reached this conclusion, from the only facts then before him, in his report on these observations.

318. But if, on the contrary, we investigate *the tonnage necessary to produce the same wear of rails on different curves,* we shall find it to be almost directly as the degree of curvature, and this is undoubtedly the true law of rail wear; from which it follows that the RATE of wear on any one curve increases as the rails become more worn, and this produces the deceptive appearance of a rate of wear varying as some function of the square of the degree of curvature.

319. As to the wear on the inner rail, it is apparent that the effect of the flange pressure (see Fig. 29, page 292) is to increase by about one third the load resting on the front outer wheel. We might accordingly expect that all the longitudinal slipping would be confined to the inner wheel which runs (see Figs. 20 to 23) with its flange entirely clear of the rail. From this we might expect (1) that the wear of the inner rail would be wholly on top, and (2) that it would be more rapid than the outer rail's. This is always found to be the case, as will be evident from Figs. 32 to 41. The excess of top wear on the inner rail would undoubtedly be much more disproportionate than it is except for this fact:

The bulk of tonnage is slow traffic, and in such cases the excess of the superelevation over the very small amount required to balance the centrifugal force ($\frac{1}{8}$ inch per degree at 15 miles per hour; see page 298) produces a slight excess of load on the inner wheels; not sufficient to counterbalance the effect of the flange pressure on the front axle, but

amply sufficient to cause the rear axle, both flanges of which stand clear of the rail, to slip entirely on the outer rail on slow trains, as being the point of least resistance.

320. We thus have this condition:

(1) The front outer wheel produces all the flange wear and little or none of the top wear,

(2) The front inner wheel produces nearly all the wear on inner rail —confined entirely to top of rail.

(3) The rear outer wheel of slow trains produces nearly all the top wear on outer rail.

(4) The rear inner wheel produces only the normal tangent wear.

321. As respects the aggregate amount of curve resistance: From all these data together we may expect it to be—

(1) 0.37 lb. per ton per degree of curvature as a minimum, varying directly with the curvature, plus—

(2) Upwards of 1 lb. per ton as a constant addition due to flange friction on new rails (assuming the coefficient of friction to be as low as 0.25, as it appears to be with car wheels. With engine-drivers it is about 0.35).

(3) As rail wear increases there will be a very considerable further addition to the resistance due to the flange wear on worn rails. This effect will become visible very much sooner on the sharper curves, but it will occur sooner or later on all curves when the flange has cut into the side of the rail.

321*a*. Let us compare these conclusions with experience:

1. Actual experiment on the 63° curves (90 feet radius) of the New York elevated railroads, conducted by Charles E. Emery, M. Am. Soc. C. E., shows the resistance to be 0.43 lb. per ton per degree of curvature on new rails with fixed wheels in the ordinary mode, and 0.33 lb. per ton with loose wheels. (If the reader will refer back to Table 109 and the accompanying discussion, he will see this to be as nearly as may be what our theory would indicate.)

2. The late Benj. H. Latrobe experimented on 14° curves, with new rails also, and found the resistance to be .40 lb. per ton.

3. French experiments with about 12-ft. wheel-bases on easy curves show about 1.25 lbs. per ton resistance.

4. The writer made, by the aid of very delicate electrical apparatus, what he believes to be the most accurate experiments on train resistance. so far as they went, which have as yet been made; and his conclusions, so far as relating to curve resistance, were that curve resistance is much

greater per degree on easy curves and at slow speeds, as shown in App. A.

322. This completes our analysis of the forces originating and acting within the truck itself, which are the only ones of importance. Let us see what, if any, effect the forces acting upon the car body and train as a whole have to modify this result.

Centrifugal force and superelevation act upon the car as a whole, and their effect is communicated to the truck through the centre-pin or side-bearings.

The centrifugal force C in lbs. per ton of any body moving at V miles per hour on a $D°$ curve we have already found to be (eq. (3), par. 271),

$$C = .02335\ V^2D, \quad \ldots \ldots \ldots \quad (1)$$

from which Table 106, page 270, was computed.

323. The superelevation of the outer rail creates a force tending to draw the car inward and to counteract the centrifugal force. The weight, by a well-known mechanical law (Fig. 44), bears the same ratio to this force as g, Fig. 43, does to the superelevation e. On a 4 ft. $8\frac{1}{2}$ in. gauge (say 4 ft. $10\frac{3}{4}$ in. centre to centre of rail) it amounts, therefore,

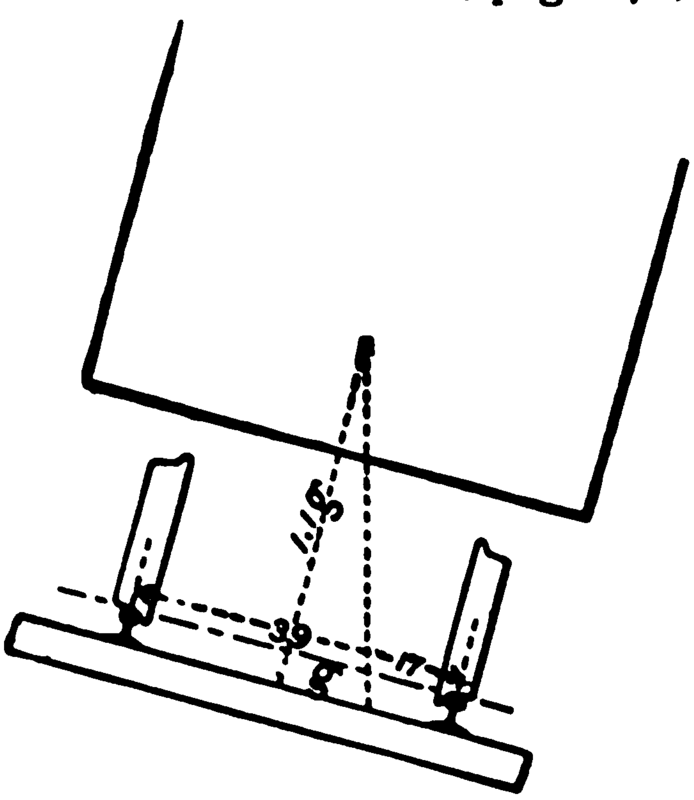


FIG. 43.

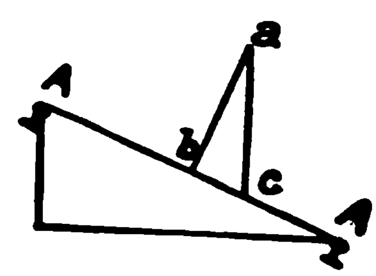


FIG. 44.

in lbs. per ton per inch of superelevation, to $\frac{1}{58.75} \times 2000 = 34.04$ lbs.

The maximum amount of elevation which is ever to be found on railways is about 8 inches, creating a force of 272.32 lbs. per ton. Many roads limit it to 6 inches, or 204.24 lbs.; but we may for safety assume the maximum to be 10 inches, or 340.4 lbs. per ton.

Comparing this with Tables 106 and 107, it will be seen to just about balance the centrifugal forces at what is marked as the maximum safe speed, according to usual practice, on various curves.

324. To determine the effect of these forces on curve resistance, let us assume the extreme case—that the maximum superelevation is en-

tirely unbalanced by centrifugal force. This is the utmost limit that safety permits.

The first effect, with the centre of gravity in the position shown in Fig. 43, is, by well understood mechanical laws, to throw $\frac{39}{56}$ or about 70 per cent of the load upon the inner rail, leaving only 30 per cent on the outer rail. This increase of load will compress the springs on the inside and by the further tipping of the car body cause the inside rail to carry three fourths or more of the total load.

The second effect is to confine all longitudinal slipping to the outside wheels as being the most lightly loaded. This, however, we have seen to be the case with the front axle under any ordinary circumstances. The lateral slip of the front axle is of course not affected.

The third effect, resulting from the combination of the above causes,

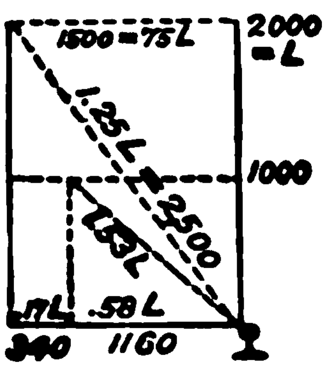


FIG. 45.—FRONT OUTER WHEEL. (The higher rectangle shows the conditions without superelevation; the smaller rectangle, with superelevation.)

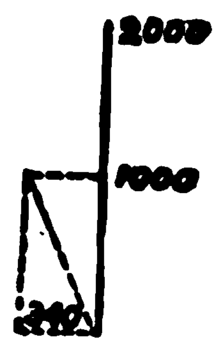


FIG. 46.—REAR OUTER WHEEL.

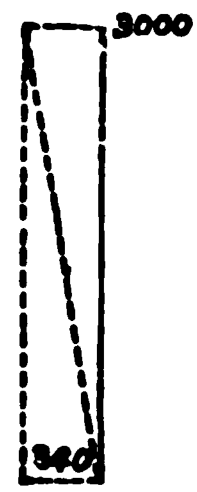


FIG. 47.—BOTH INNER WHEELS.

is to change the magnitude and direction of the forces acting on each wheel in the manner shown in Figs. 45 to 47, in which the solid lines show the magnitude and direction of the forces already determined, independent of the superelevation.

Or, in other words, taking from Table 109, page 286, the slippage which regularly takes place in a 5-foot wheel-base on a 10° curve, we have—

	Slippage in feet per 100 feet.	Increase of Load.	New Slip.
Rear inner wheel........	0.00	50 per cent. increase.	0.00
" outer "	0.82	50 " " decrease.	0.41
Front inner "	0.89	50 " " increase.	1.33
" outer "	1.21	39 " " decrease.	.74
Total amount............	2.92	15 per cent. decrease.	2.48

The further resistance from flange friction on the front outer wheel (as also flange rail wear) should also be diminished about 39 per cent.

325. We thus see grounds for believing that the general effect of even an extreme amount of unbalanced superelevation may be to somewhat decrease the resistance, but not to any important extent; and with the ordinary and proper limit of 6 or 7 inches superelevation, partially balanced, as it always is in practice, by centrifugal force, the effect becomes almost insignificant one way or the other, although still apparently to decrease the resistance so far as it has any effect at all. On the other hand, a similar computation to the above as to the effect of an unbalanced centrifugal force will indicate that it has a very similar and equally inconsiderable effect to increase the resistance. Fig. 48 shows the most objectionable effect from excess of centrifugal force. (See par. 327.)

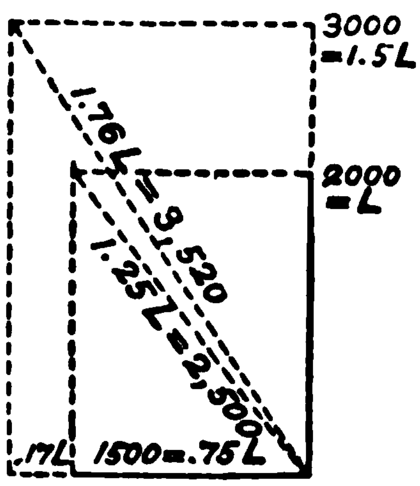


FIG. 48.—EFFECT OF UNBALANCED CENTRIFUGAL FORCE ON REACTION OF FRONT OUTER WHEEL AGAINST RAIL. (Compare Fig. 45, showing effect of an equal amount of unbalanced centripetal force from superelevation.) See Table 106 for velocity necessary to produce this amount of centrifugal force.

326. Let us now see what effect such unbalanced forces do not have. They do not alter in any manner whatsoever the position of any of the wheels, nor can they by any possibility do so, it would appear, until the centrifugal or centripetal force becomes a force so great that it would slide the wheels laterally on the track if the car were standing still on the rails, which would be when the superelevation was equal to the *coeff. fric.* × *gauge*, or at, say, $\frac{1}{4}$ gauge, or about 14 inches. For the force required to slide a rolling wheel on the rail, either laterally or longitudinally, is neither greater nor less than if the wheel were standing still (unless there may be some slight and unknown modification of the coefficient of friction); and so long as the force is not FULLY sufficient to do this, it has no effect at all to move the body. All it can do is to increase or decrease the pressure of the flange against the outside rail, and this (within the limits of safe and customary practice) only to a trifling extent. This results from an elementary mechanical law which has been too readily lost sight of by theorizers on this subject, that a lifting force of 1999 pounds is as incapable of lifting a ton as a force of one pound.

327. The real objection to too much superelevation, or to too high velocity, is its effect upon safety. Throwing so much weight upon one rail and one set of springs, is, if carried to excess, highly dangerous, although

the resistance is not in any case very seriously affected. An excess of superelevation would appear to be the least evil of the two, however, in all respects, for we have seen (par. 324) that it has probably some slight effect to decrease the resistance of the slowest freight train.

328. The contrary assumption is very general, but it is absolutely unsupported by experimental evidence so far as the writer can discover, and it certainly finds little defence in theory. The truth is, that much of the current and almost endless discussion of this topic among road-masters and even engineers has its root in insufficient examination of the mechanics of the problem. It is ASSUMED that the two obtrusively evident forces, centrifugal force and its opposite, are the only ones to be considered, and that the truck is thrown against one rail or the other by these forces according as either force preponderates. Yet one has only to watch the wear of rails and the motion of a truck around a curve to find that there is some force independent of either (which we have analyzed at length) which presses the outer wheel against the rail with tremendous force, however high the superelevation; and from this it follows that it is the effect of the other two central forces *upon this force* which is the real problem to be considered.

329. WE CONCLUDE, therefore, that the centrifugal and centripetal forces have but a trifling effect on curve resistance, and that the proper rule for superelevation is to elevate sufficiently to balance the centrifugal force of the fastest trains up to a maximum of six to eight inches. This will slightly decrease the resistance and danger of accident to freight trains, and greatly improve the comfortable riding of passenger coaches, provided always that some uniform rule be followed, since almost any rule is better than none.

330. A third source of possible curve resistance, OBLIQUITY OF TRACTION, affects the train as a whole. The conditions of the problem are presented in Fig. 49.

It may now be considered as established that, despite a prevalent impression to the contrary (which many able engineers have shared), no loss of power whatever occurs from this cause. Let OA, Fig. 49, represent the tractive force to be transmitted through the coupling O to the car B. As there is a change of direction in the force at O, it is sometimes claimed

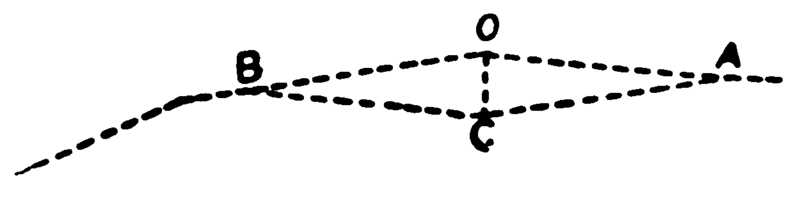


FIG. 49.

that no force OA can be caused to act on the following car in the changed direction OB without a certain loss of tractive force, and hence waste of energy. This position is in both respects unsound. There is no loss of tractive force at each car *due to obliquity of traction*, and, even if there were, it would not necessarily imply any waste of energy. It follows that the method of analyzing the strains by which such position is supported (which consists in making the angle OCA, Fig. 49, a right angle and then taking the force $OB = AC$, or less than OA) is incorrect.

331. The correct way of representing the action of the forces involved is by the parallelogram of forces shown in Fig. 49, which should be constructed as shown, with $OB = OA$, the force OA being transmitted undiminished through O as around a pulley; the lateral stress OC having no more effect to reduce the force OB than the stress OC, Fig. 50, has to make the force OB less than OA. Both in Figs. 49 and 50, if the stress OC is sufficient to produce lateral motion in the direction OC by overcoming the static resistance, it will or may consume power, and the force OB may be then quite different from AO, but otherwise not.

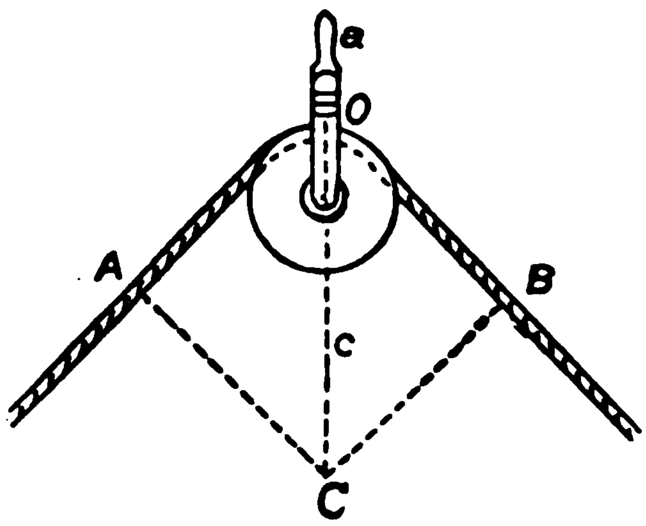


FIG. 50.

In a train of cars, the lateral component has only the effect to minutely increase the lateral resultant of the superelevation, which we have just seen tends to decrease the resistance (if anything), but has no effect to change the position of any wheel, or to increase perceptibly the pressure of the wheels against the rails.

Conceive the track to be a complete circle, and the train to completely fill it. Conceive the floor of the cars to be a rigid continuous circular platform. There would then nowhere be a lateral resultant of the kind discussed, but no reason is apparent why the curve resistance should be either greater or less.

332. The transmission of force from car to car, through a train on a curve, is an almost exact mechanical parallel to the transmission of power by a rope or chain over a pulley; the rope being the string of car bodies, and the car wheels the pulleys. The fact that the pulleys are carried by the rope itself, instead of in a block exterior to it, is a mere detail not affecting the mechanical conditions. In either case the loss from such transmission is simply the friction of the pulley. Conceive a chain made of successive links, each carrying a pulley wheel and being

dragged over a large cylinder or succession of cylinders, large or small. Conceive, further, the rope to be so long and the friction of the pulleys so great that the whole power of the prime mover is consumed in keeping the chain in motion at uniform speed. We have here a perfect mechanical parallel to a train in motion on a curve, except for the one minor fact that the resultant of all the forces acting on the wheels does not, in case of a railroad train, lie exactly (although it does nearly) in the plane of the wheels themselves, whereas in the case of the pulley wheels it does. But no resistance arises at the coupling-points from "change of direction," or obliquity of traction, or from any other source than the friction of the pulleys proper, in either case. It is, of course, true that the resistance of the rear pulleys would tend to press each pulley in advance more tightly against the surface, and so produce greater friction in the pulley itself than would otherwise exist; and similarly in the case of a railroad train it is entirely pertinent to prove that a lateral centripetal force is produced by obliquity of traction, so that the resultant of all forces does not lie in the plane of the wheel, and that this fact produces greater friction. The latter, however,—the only possibility pertinent to discuss,—is commonly neglected in discussions which assume that lateral resultants from obliquity of traction indicate *from their mere existence* a loss of energy. FORCE, i.e., static stress, is one thing, RESISTANCE, i.e., destruction of dynamic energy, is another and quite different thing. We cannot figure away energy with a parallelogram of forces, but must prove when and how, if at all, it is lost by additional friction. As a matter of fact there appears to be no loss, but a trifling gain, under ordinary conditions, from the fact that the centripetal tendency is increased.

333. There is so much misconception as to this matter that we may endeavor to make it still clearer. In Fig. 51 let the lines *OOP* represent the axes of two successive cars moving in either direction; *PP*, the two coupling-pins; and *L*, the coupling-link. Let the lines *SS* represent in magnitude and direction the tensile force acting upon the link and tending to rupture it. As a matter of course, these forces *S* must be equal to

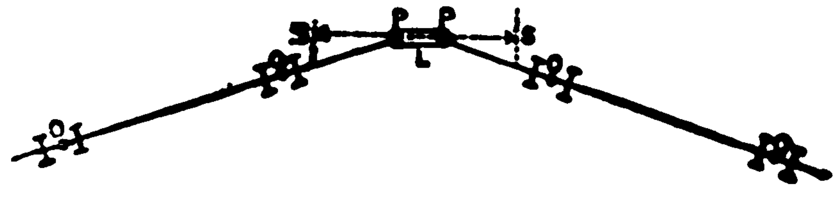


FIG. 51.

each other, since action and reaction are equal, and when resolved into forces acting along the axes of the cars this makes the latter also equal. The losses of tensile force from car to car occur at the centre-pins *O* of each car, and not at the coupling points *P*. The tension on the front end and back end of the draw gear of any given car is always different by the amount of the frictional resistance of that car; but the longitudinal strains, parallel with the respective

axes of the cars, on the rear draw-gear of a forward car and the front draw-gear of a rear car, are always equal to each other in magnitude, although different in direction by the amount of the angle between the axes. That is to say, the diminution of tensile force from car to car is internal to each car, and not at all at the coupling-point.

334. But the point is not worth disputing, for the loss, if it were granted to exist, is very small. Assuming the car body to be 30 feet long, the deflection angle *OAC*, Fig. 49, will evidently be, on a $D°$ curve, $0.3D$ or $18' \times D$, and of the tractive force F ($= OA$, Fig. 49) there will be an assumed loss, which let $= L$, at each coupling, from obliquity of traction:

$$L = F\,(1 - \cos 18')\,D = 0.000016DF.$$

The tractive force of a Consolidation engine is something over 20,000 lbs. at the engine and zero at the end of the train, averaging, say, 10,000 lbs. Then the loss per car will average, on a 1° curve,

$$L = 0.16 \text{ lb. per car,}$$

or, on a 10° curve with a 60-car train,

$$L = 96 \text{ lbs.}$$

Not a very serious matter, certainly.

335. We conclude, therefore, as to curve resistance:

1. Obliquity of traction and the length of the train have no appreciable effect to modify curve resistance.

2. Centrifugal force within the limits of practice has but little effect on the resistance, but that little is to increase it.

3. Centripetal force from superelevation within the limits of safe practice has but little effect on the resistance, but that little is to reduce it.

4. The best rule for superelevation is to elevate for the fastest regular speed up to a maximum limit of 6 to 8 inches in all.

5. Rail wear and curve resistance over rails in the same condition are as nearly as may be directly as the degree of curvature, with some minor elements which are independent of radius.

6. Rail wear and curve resistance are appreciably less with new rails than with old, and become greater as the outer rail is worn away to the shape of the flange.

7. The pressure of the flanges against the rail is the same on all curves independent of radius, but the wheel stands at a

greater angle to the rail as the curve is sharper, and likewise is sliding faster on the surface of the rail, increasing the danger of derailment correspondingly, by some unknown amount, but not nearly in proportion to the degree of the curve.

8. The lowest probable limit of curve resistance at ordinary freight speeds and in ordinary curves is about $\frac{1}{3}$ lb. per ton per degree of curve, with all in perfect order. With worn rails and somewhat rough track it may be as high as $\frac{3}{5}$ lb. per ton.

9. While so obscure a point cannot be considered as established by the existing experimental evidence, all the more trustworthy existing evidence seems to combine with theory to indicate that curve resistance per degree of curve is very much greater on easy curves than on sharp curves; so that when the resistance is 1 lb. per ton, for example, on a 1° curve, it may be 6 to 8 lbs. per ton on a 10° curve, and not more than 15 to 18 lbs. per ton on a 40° to 50° curve. (See Appendix A.)

10. It may be considered established that curve resistance is affected somewhat by the speed, and probably by a very considable percentage; so that if the curve resistance in motion be $\frac{1}{2}$ lb. per ton it may be as high as 1 lb. per ton on worn rails, for speeds of less than 4 or 5 miles per hour, or for the first train length or thereabout in getting under way. As a stoppage on any curve is always a possibility, this contingency should not be forgotten when reducing grade on curves, especially near possible stopping points.

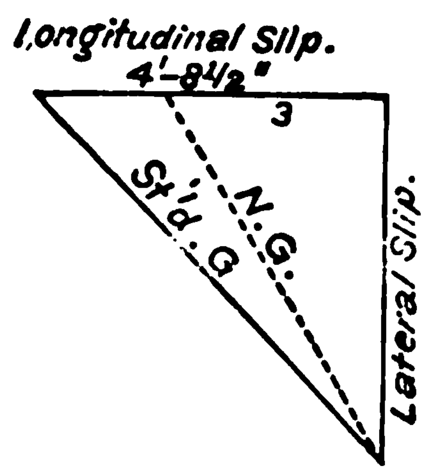


FIG. 52.—EFFECT OF DIFFERENCE OF GAUGE ON CURVE RESISTANCE, LENGTH OF WHEEL-BASE REMAINING THE SAME. (The comparative slipping of the wheels in a given distance is represented by the two diagonals marked *N. G.* and *St'd. G.*)

11. The beneficial effect of the narrower gauge is small with the same length of wheel-base. With a 3-ft. gauge as against a 4.7-ft. gauge, with a wheel-base of 4.7 ft., it is about as (not exactly as) $\frac{\sqrt{4.7^2 + 4.7^2}}{\sqrt{3^2 + 4.7^2}} = \frac{6.647}{5.576} = \frac{1}{6}$ less, as outlined in Fig. 52. With a wheel-base of $2g$ the gain is only $\frac{110.72}{97.36} = 12$ per cent less. If, however, the length of wheel-base decreases with the gauge

the gain is directly as the gauge. All the preceding refers only to the surface friction on the top of rail, flange friction being much less affected.

12. Increasing the length of wheel-base, say, from *gauge* to 2 *gauge* increases curve friction as outlined in Fig. 53, in the ratio of $\frac{2.236}{1.414} = 58$ per cent.

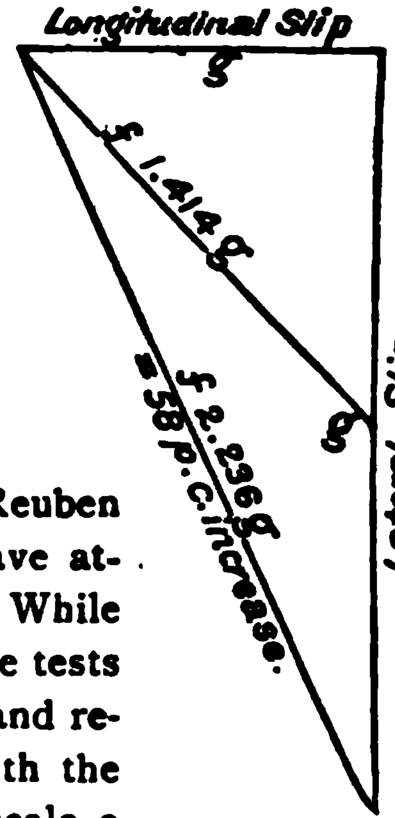


FIG. 53.—EFFECT OF DIFFERENCE OF LENGTH OF WHEEL-BASE ON CURVE RESISTANCE, GAUGE REMAINING THE SAME.

336. Perhaps the best existing experimental confirmation of the eleventh conclusion above is to be found in some delicate experiments on models by Mr. Reuben Wells (Rept. Am. Ry. M. M. Assoc., 1876), which have attracted far less attention than their merit deserves. While no one test of any kind can be considered decisive, the tests do afford an indication which is perhaps more delicate and reliable as a test of principle than could easily be made with the actual rolling-stock. With trucks representing to $\frac{1}{16}$ scale a wheel-base of 4 ft. 10 in. and gauges of 3 ft. and 4 ft. 8½ in. on a curve representing to the same scale one of 300 ft. radius and 273 ft. long, gravity being the impelling force, Mr. Wells found—

Speed. Miles Per Hour.	Resistance; lbs. per ton (actual). St. G.	N. G.	p. c. of N. G.
5.76	46.80	39.14	83.6
7.59	48.96	41.66	85.1
10.12	45.76	41.66	91.0
16.70	68.20	64.40	96.0

By formula above $\sqrt{gauge^2 + wheel\text{-}base^2}$ the per cent of N. G. should be, uniformly, 82.7 p. c.

If we consider that in these observed resistances the normal tangent rolling friction is included, whereas in the formula it is not, the two correspond wonderfully closely, indicating, however, that the absolute amount of curve resistance decreases with the speed—which is probable from other reasons. The tests were made by raising the track to a grade which would give the desired velocity and the resistances in lbs. per ton deduced therefrom. The high absolute amount of the latter, compared with normal rolling-stock resistance, should not be allowed to convey an impression that the models were rough. On the contrary, they show that it was very delicately constructed, as the resistances *per ton* of its actual weight are but little more than three times what might be expected with fully loaded cars, which is even less than the probable difference in coefficient of friction due to the difference of load.

Mr Wells's primary purpose in undertaking these tests was to determine how much there might be in the alleged theoretical advantages of loose wheels

for passing curves. He found that in no case was much gained, while in some cases the loose wheels were a positive disadvantage. The preceding theoretical discussion of the mechanics of curve resistance may be readily shown to point directly to the same conclusion, and almost to Mr. Wells's identical figures, had it appeared expedient to extend this discussion for that purpose.

337. The late Baron Von Weber, whose great services to the cause of science entitle anything vouched for by him to a presumption in its favor, gave currency to a very absurd formula in respect to curve resistance, which has been quite extensively quoted as trustworthy, as it was alleged to rest on some extensive and elaborate experiments. This formula gave the total resistance as a function of $\frac{C}{R - 55}$, R being the radius in metres. This formula gives resistances increasing much faster than the degree of curve, instead of slower, as we have found; the results varying from a resistance of 0.8 lb. per net ton per degree for a curve of 1000 metres radius (3310 ft., or 1° 44′) to a resistance of 1.67 lbs. per net ton per degree for curves of 100 metres radius (331 ft., or 17° 20′). But by extending the formula to a little sharper curves its untrustworthy and absurd nature is at once seen. For a curve of 60 metres radius (197 ft.) we obtain a resistance 9.45 times as much per degree as on a curve of 1000 metres radius, and for a curve of 55 metres radius or less an infinite resistance. As the curves of the New York elevated railways are of less than 30 metres radius, and as ordinary American engines were operated over a curve of 50 ft. radius for some time without accident or delay, on the United States Military Railroads in the late war, this is hardly a rational result.

338. A new and dangerous doctrine has lately been advanced, in a semi-official manner which has given it wide currency as a conclusion of the Master Car-Builders' Association, although it was in no sense such in fact, viz., that the corners of rails should be rolled to a larger radius (¾ inch) so as to exactly fit the radius of the fillet or interior corner of the flange, instead of the two being of quite dissimilar radius, as in Fig. 31, which shows the more usual and the only proper practice.

FIG. 54.

(FIG. 54 is FIG. 10 of Mr. Forney's paper, "The Relation of Railroad Wheels and Rails to each other," and shows a New York Central rail-head and a flange with a fillet of ¾ inch radius.)

These conclusions were expressed in an otherwise able paper, by M. N. Forney, Secretary of the Association (Rept. M. C. B. Assoc., 1885); and the theory was based upon the claim that the usual form of rail and flange, such as is shown in Figs. 30 and 31, causes sharp flanges, producing wear such as is outlined in Fig. 54; the corner of the

rail wearing to a larger radius, and the fillet of the flange to a smaller radius, thus producing sharp flanges.

The facts are:

1. (See Table 114.) Only a very small percentage of wheels ever get sharp flanges, and there are never two sharp flanges on one axle; showing that some mechanical defect of wheel or truck (usually the latter) is the chief cause of sharp flanges, and not some general cause acting upon all wheels alike.

2. Except in the one case of the outside rail on curves, rails invariably wear to a much smaller corner radius, as in Fig. 55, reproduced from an example of wear in Mr. Forney's paper (see also Figs. 32 to 41), and never in the manner outlined in Fig. 54.

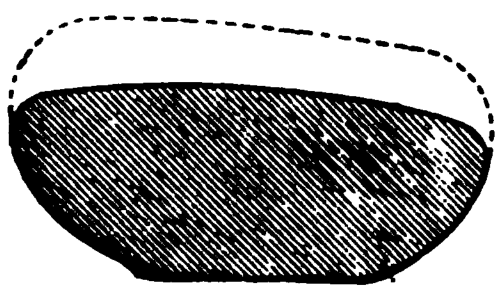


Fig. 55.

3. In the one case of the outside rail on curves the rails do finally wear away in something like the manner outlined in Fig. 54, until the side of the rail takes almost the exact form of the flange, as in Fig. 41, but there is then much more friction, more rapid wear, and more danger of derailment than when the rails are new, as in Figs. 31 or 54; because, although the bearing surface is small in the latter case, it is subjected to only rolling wear, whereas if the flange fits all around the rail corner the additional bearing surface is exposed to rubbing friction. (See par. 313 *et seq.*)

339. Imagine a heavy sphere rolling down a plank, as in Fig. 56. It has a very small bearing surface, yet any additional bearing surface which might be gained by turning the plank into a trough "exactly fitting" the sphere would plainly produce more friction and more wear, rather than less. The same conditions obtain in Fig. 54, where the material outside the dotted lines, which it is proposed to remove in first manufacture, is really "precious metal," serving to long postpone the day when the rail and flange fit as Fig. 41, and a very rapid rate of wear begins. The metal outside the dotted lines in Fig. 54 will require at least *four times* as great a tonnage to wear it away as will be required to wear away an equal weight of metal after it is gone. Moreover, the wear of flange outlined in Fig. 54 never takes place at all except in a very small percentage of the wheels (2 to 6 per cent), indicating that it is not due, when it does take place, to the form of the rail.

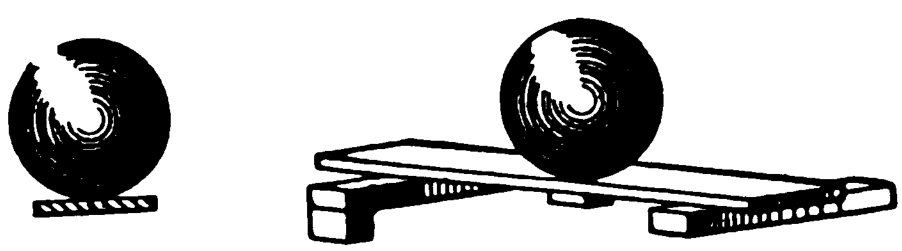


Fig. 56.

340. What sound practice would seem to require, therefore, is:

1. The tread of the wheel should have something the form of Fig. 57, with a fillet radius of at least ⅝ in., instead of the ½-in. radius which Mr. Forney

recommended, and the $\frac{5}{8}$-in. radius which the Master Car-Builders' Association have unfortunately adopted as standard.

2. The original corner radius of the rail should be little if any greater than $\frac{1}{4}$ or $\frac{5}{16}$ in.

In this way we shall postpone as long as possible the evil day when the rail and wheel will not simply roll upon but grind into each other.

341. The deleterious effect of having the corner of the rail of larger radius than the fillet of the flange is clearly visible in Fig. 58. When any lateral flange pressure arises from the passage of a curve or other cause, instead of the bearing surfaces being able to still maintain the merely rolling contact of minimum wear, as outlined in Figs. 31 and 59, we have the *rubbing* side contact shown in Fig. 58, sure to produce rapid side wear, in addition to the usual top sliding and wear. This has actually resulted with rails of such form. On the Lehigh Valley and on the parts of the Pennsylvania laid with its new rail section of $\frac{3}{8}$ in. corner radius, both rails, on both curves and tangents, are badly worn far down the side of the rail, as if laid very tight of gauge, whereas with rails of the usual form this never results, however old or worn the rails, except on the outside rail of curves.

FIG. 59.

342. Mr. M. N. Forney, in the paper above referred to (par. 338), gives the best existing evidence as to the effect of coning on the natural path of trucks having parallel axles. He experimented with an apparatus such as is shown in Fig. 60. To determine positively if these results were correct, the writer has since constructed and tested a model of quite different form with closely similar results.

Mr. Forney's model, compared with a full sized truck, was made to a scale of $\frac{1}{2}$ in. $=$ 1 foot, or $\frac{1}{24}$ of full size. The wheels on each axle represented full-sized wheels of $34\frac{1}{2}$ and $31\frac{1}{2}$ in., or a difference of 3 in. in diameter. The radii of the actual path of the model, with wheels set at various distances apart, are shown in Fig. 61. Converting all the dimensions of the model and the results of the experiments into the full size which they represented, they indicate that a single pair of wheels on the same axle, with a difference of 3 in

Fig. 57.

Fig. 58.—Rail Section and Wheel-tread, Lehigh Valley Railroad.
(Showing effect of having corner of rail of larger radius than fillet of flange.)

in their diameters, will roll in a curve of $53\frac{1}{3}$ ft. radius. Two pairs of such wheels, if the axles are held parallel, as in the model, would roll in the following curves:

Axles	3 ft.	apart will	roll in a	curve of	67 ft.	radius.
"	4	"	"	"	$91\frac{1}{2}$	"
"	5	"	"	"	133	"
"	6	"	"	"	$174\frac{1}{3}$	"
"	7	"	"	"	251	"
"	8	"	"	"	$337\frac{3}{4}$	"
"	9	"	"	"	479	"
"	10	"	"	"	$643\frac{1}{2}$	"

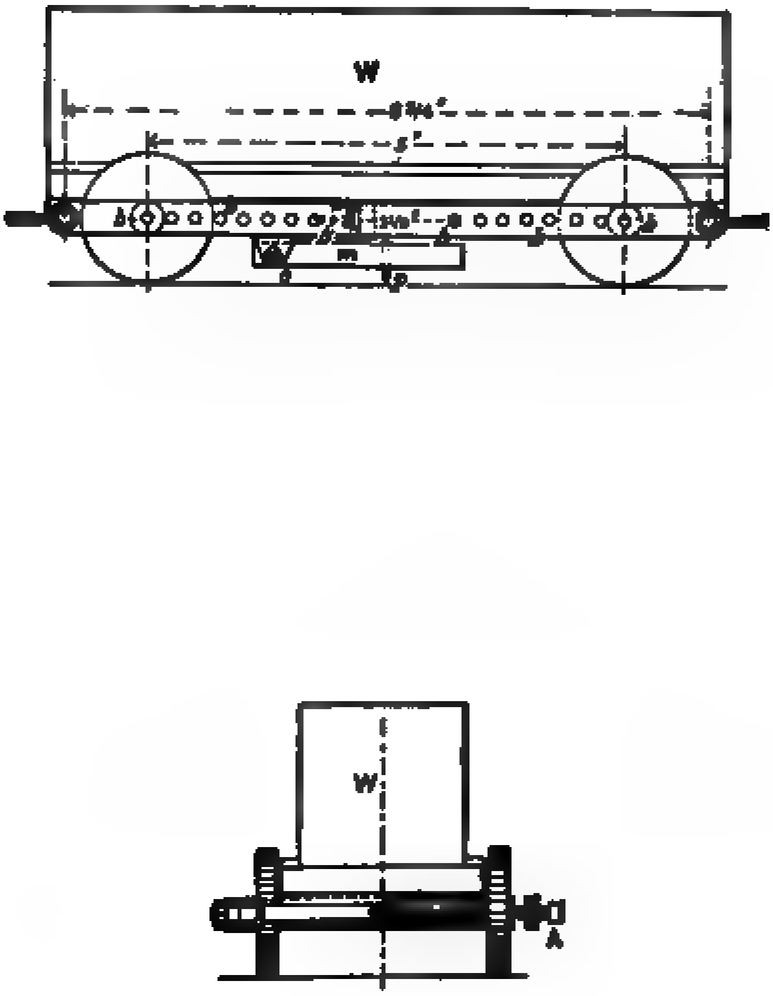
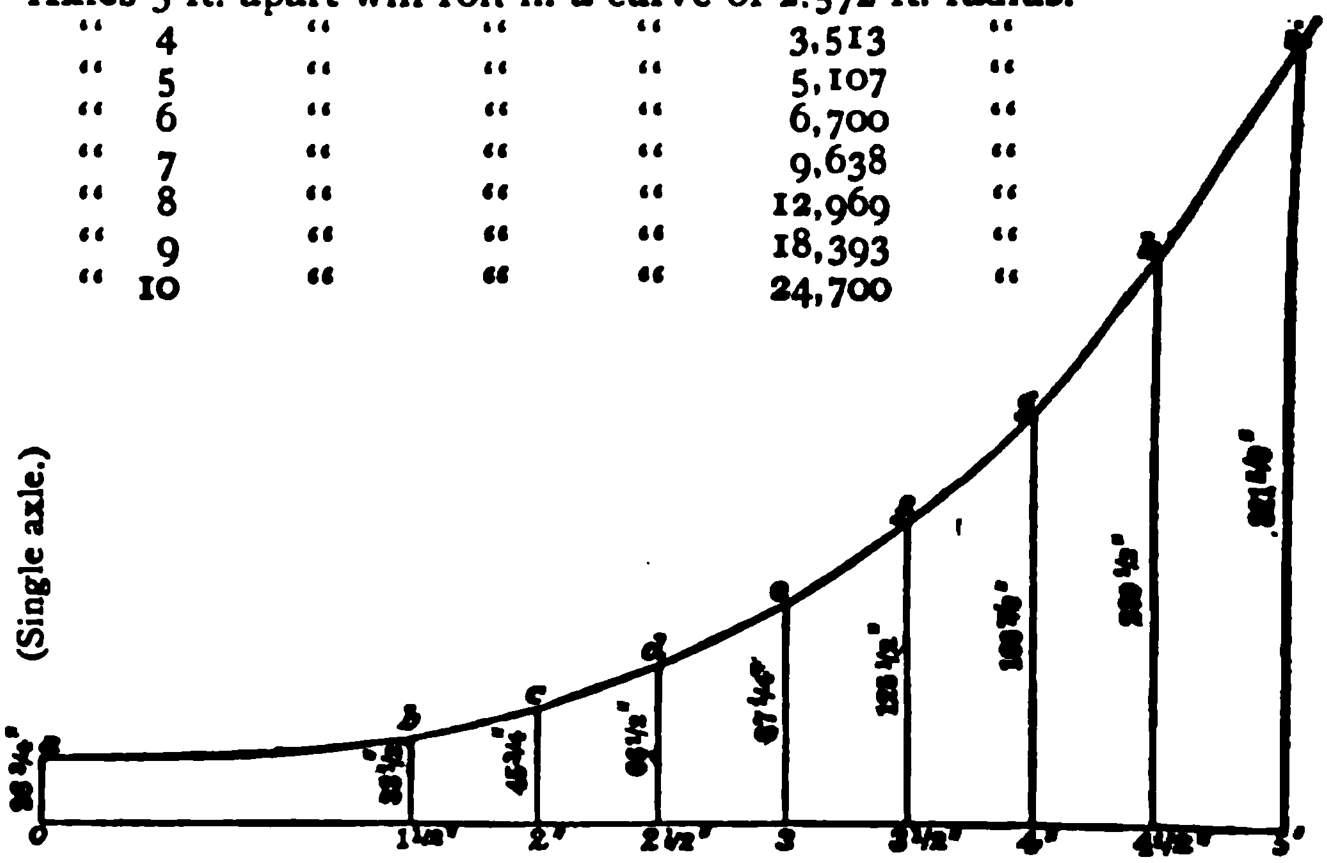


Fig. 60.—Model used by Mr. M. N. Forney for Investigating the Effect of Coning on the Path of Rectangular Wheel-bases.

With an average coning of $\frac{1}{16}$ in. in the length of the tread, and an average play in the gauge of $\frac{3}{8}$ in., we find about $\frac{1}{16}$ in. to be the difference of diameter which ordinary coned car wheels can have, assuming that both wheels stood

close to the outside rail, which they do not (see Fig. 20 and par. 294). This would correspond to results in actual practice as follows :

Axles	3	ft. apart	will roll in	a curve of	2.572	ft. radius.
"	4	"	"	"	3.513	"
"	5	"	"	"	5.107	"
"	6	"	"	"	6.700	"
"	7	"	"	"	9.638	"
"	8	"	"	"	12.969	"
"	9	"	"	"	18.393	"
"	10	"	"	"	24.700	"



Gauge, 2.35 in.

FIG. 61.—RADIUS OF PATH OF WHEEL-BASE SHOWN IN FIG. 60, WITH WHEELS SET AT VARIOUS DISTANCES APART, AS SHOWN ALONG THE BASE-LINE.

These figures indicate that even under the most favorable possible circumstances coning can have little effect to facilitate the passage of curves.

343. Having now investigated the nature of rail wear on curves and the causes of curve resistance, we are better prepared to take up and estimate at their true worth the positive objections to curvature, as summarized at the beginning of this chapter, which are :

1. THE DIRECT COST OF CURVATURE of various radii; that is to say, the greater wear and tear of road-bed and rolling-stock, and the greater consumption of fuel.

2. THE LIMITING EFFECT OF CURVATURE on the weight and length of trains.

A moment's consideration will show that these two causes of expense are sharply defined from each other. For every curve, whether sharp or flat, and wherever situated, must cause a certain amount of wear and tear and waste of power, although

it may not cause any shorter trains to be hauled, which is its DIRECT effect on expenses; but if the curvature be very sharp or very unfavorably situated, or if the line be very nearly level, so that there are no heavy grades to limit trains in advance of curvature, there will finally come a point where too much or too sharp curvature will not only cause wear and tear, but likewise cause the length of trains to be cut down. In that case the direct expense of the curvature, for wear and tear and waste of fuel, will continue on as before, but there will now be a new source of expense added to that which exists on all curves without distinction.

We for the present (until Chaps. XVIII. and XIX.) consider only these DIRECT sources of expense which are common to all curvature wherever situated, assuming that it does not require more trains to be run, but simply makes it more expensive to run them.

THE EFFECT OF CURVATURE ON OPERATING EXPENSES.

344. FUEL.—We have already seen (par. 186) that about 33 per cent of the cost of fuel goes for getting up steam, kindling fires, running to and from trains, stopping and starting trains, standing idle, etc., etc., and is hence a constant wastage, independent of the distance run. All of this may be considered as likewise unaffected by curvature, and in addition thereto there is another and important source of loss, viz., condensation due to radiation of heat, which varies with the time of exposure, and hence with the distance run, but is inappreciably affected by the power developed per hour. Every part of a locomotive, even the lagging, is hot enough to burn the hand in the coldest weather.

The fire-box is usually left entirely exposed (by a mistaken negligence, which is gradually being corrected in some few instances, as on the Lake Shore & Michigan Southern Railway, on which all the fire-boxes are lagged *), and the ends of the cylinders are protected only by metal plates. As a consequence, the average amount of fuel consumed in winter is shown by abundant statistics to be very uniformly about 20 per cent greater than in summer, or about 1 per cent for each 2° F. difference of temperature.

* It is claimed that an economy of some 10 per cent in fuel was attained on the Lake Shore by such lagging of the fire-box. Am. Ry. M. M. Rep't, 1885.

345. To appreciate the full force of this fact, we must remember that the hottest summer day is cold to the cylinders and boiler. The temperature within the boiler is about 350° F.; and hence whether the temperature outside be 0° F. or 100° F. makes little proportionate difference.

Let us suppose the average fuel consumption in July, with an average temperature of 77° F., to be 60 lbs. per mile. In January, with an average temperature of 37° F., experience shows that the consumption will be some 20 per cent greater. Then we have:

	Temperature.			
	Interior.	Exterior.	Difference.	Lbs. Coal Burned Per Mile.
July,	350°	77°	273°	60
January,	350°	37°	313°	72
Increase p. c.,		40°	14.6 p. c.	20 p. c.

The cause of this enormous effect of difference of temperature is very obscure, and it would lead us too far to discuss it in detail. The matter has attracted far less attention than it should, and even the facts from which any discussion of causes must start are but little known to railroad men. It will be seen that, superficially considered, the facts seem to indicate that a very large proportion of the fuel consumption is due to the effects of exterior temperature; for if a decrease of 40° F. or 1½ per cent in the difference between the temperature within and without the boiler saves 20 per cent of the fuel, it would seem as if we had only to decrease the difference a little farther to save half or three quarters of it.

This conclusion would be absurd, but all that it is desired here to show is that exterior radiation is a very serious matter. The chief causes for the great difference in winter and summer fuel consumption are probably these:

1. The rolling friction is considerably higher. Most of the energy destroyed by friction must take the form of heat, and as the journals speedily attain about the same temperature in both winter and summer (moderately warm to the touch) the difference in temperature of the journals and the external air is much greater in winter, and this means so much more journal friction.

This theoretical deduction lacks, as yet, direct experimental evidence, pending which it must be regarded as doubtful. By some strange omission, the comparative winter and summer train resistance has not been the subject of direct investigation, so far as the writer is aware; but that there is considerable difference appears to be indicated by the fact that it is found necessary in prac-

tical operation to cut down trains in winter by about 10 per cent (say from 20 cars to 18, or from 40 cars to 36), for which it is difficult to imagine any other rational explanation. The popular explanations are: (1) That the wind travels more miles in winter than in summer, which is not true; and (2) that the track is in worse condition, which is unquestionably true to some extent; but there are very few days when snow and ice cause much trouble on the surface of the rail, which is for the most part as clean in winter as in summer, and the effect of heaving of the road-bed on train resistance, although important, can hardly account for the difference which exists.

346. Internal radiation also, from the hot steam, when first admitted to the cylinder, into the interior walls thereof,—whence it is almost instantly returned again into the exhaust steam, as the temperature falls from reduction of pressure, without having done any work,—is admitted to be a very great source of waste, but is entirely distinct from the external radiation, for it is not appreciably affected by the external temperature, and does vary with the power demanded, and inversely with the speed; in all of which details it differs from external radiation.

It is true that a locomotive standing still and not using steam loses but a trifling amount from radiation (about 30 lbs. per hour); but the conditions are vastly different when working against a fierce wind with every part to be kept hot, and it is difficult to resist the evidence that at least $\frac{1}{6}$ of the fuel consumed goes to replace radiated heat. If so, as $33\frac{1}{3}$ per cent goes for other causes of wastage, we have 50 per cent of the fuel left as that portion which varies directly with the power demanded. Possibly it is still less, but it can hardly be much more.

The correctness of this conclusion is indicated, in a measure, by the coal burned by engines running light. An engine which will burn 60 to 80 lbs. per mile with its full train, will burn 20 to 30 lbs. per mile only to run itself.

347. Assuming curve resistance to average about $\frac{1}{2}$ lb. per ton, it is perhaps as correct an average as possible to say that a continuous $11° 20'$ curve causes an average additional train resistance of about 6 lbs. per ton, or about doubles the resistance of a train on a level. A mile in length of such a curve contains 600° of curvature.

We may say, therefore, that 600° of curvature will waste about 50 per cent as much fuel as the average burned per mile run.

348. REPAIRS OF ENGINES.—Referring to Table 85, page 203, it will be seen that the proportion of this item assignable to the average effect of curvature and grades is about 19 per cent, nearly all of it arising from wear of wheels and tires. Experimental data as to the actual effect of either grades or curvature on locomotive or car repairs are very few. Statistics of actual expenditures for such purposes on lines differing con-

TABLE 114.—*Continued.*

CLASS 3.—TWELVE WORST MAKERS—AGGREGATING ONLY 4.6 PER CENT OF WHEELS IN SERVICE.

13	.9	71.9	72.8	0.0	0.0	22.3	4.9	100.	14.40
14	3.4	59.3	62.7	0.0	0.0	23.7	13.6	100.	3.76
**15	10.4	19.6	30.0	0.3	14.2	11.9	43.6	100.	90.5
*16	0.0	0.0	0.0	0.0	54.6	45.4	0.0	100.	35.7
***17	6.3	21.9	28.2	0.0	21.8	9.4	40.6	100.	12.62
**18	4.9	14.5	19.4	0.0	24.1	17.8	38.7	100.	19.1
**19	7.9	8.6	16.5	0.0	9.3	14.3	59.9	100.	76.9
*20	1.6	22.9	24.5	0.0	4.9	15.6	55.0	100.	14.1
*21	6.0	36.2	42.2	0.5	4.6	17.4	35.3	100.	28.9
22	0.2	88.8	90.0	0.0	1.6	7.0	1.4	100.	25.2
23	5.8	26.4	32.2	0.0	3.3	49.6	14.9	100.	5.00
***24	7.5	4.5	12.0	0.0	8.9	44.7	34.4	100.	2.29
Average	4.4	37.2	41.6	0.0	12.4	20.3	25.7	100.	20.16

Bold-face numbers represent makers having from 20,000 to 50,000 wheels each in service. *Starred* numbers indicate the smaller makers, viz., * Less than 1000 in service; ** less than 500 in service; *** less than 300 in service.

SUMMARY.

	Six Best Makers.	Six Next Best.	Twelve Worst Makers.	Av. of all on Road.
Per cent of whole number in service..........	76.2	17.2	4.6	100.0
Broken	2.0	2.2	4.4	2.4
Cracked	12.2	23.7	37.2	19.4
Broken and cracked	14.2	25.9	41.6	21.8
Shelled out	[illegible]	0.1	0.0	0.4
Sharp flange	2.[illegible]	8.2	12.4	5.8
Slid flat	22.3	22.1	20.3	21.7
Worn flat and worn out..........	50.1	44.7	25.7	50.3
Total removed	100.0	100.0	100.0	100.0
Per cent of number in service removed ..	4.30	10.34	20.16	6.22

PERCENTAGE OF TOTAL NUMBER IN SERVICE REMOVED FOR EACH CAUSE.

	Six Best Makers.	Six Next Best.	Twelve Worst.	Total.
Per cent of whole number in service..	76.2	17.2	4.6	100.0
Broken	[illegible]	0.23	0.88	0.15
Cracked	[illegible]	[illegible]	7.50	1.20
Broken and cracked	[illegible]	2.83	8.38	1.35
Shelled out	[illegible]	[illegible]	0.00	0.02
Sharp flange	[illegible]	[illegible]	2.50	0.36
Slid flat	[illegible]	2.32	4.10	1.35
Worn flat and worn out	[illegible]	4.30	5.18	3.13
Total removed	4.30	10.34	20.16	6.22

While the above table gives valuable and trustworthy indications of the *relative* qualities of different makers, *it gives an entirely false idea of the* ABSOLUTE *qualities of American chilled car wheels*, unless a large allowance is made for the fact that it is modified immensely by the constant annual additions of new stock. This is immediately evident in the total number removed for all causes, which is only 6.21 per cent of those in service, indicating on its face an average *life of sixteen years*, which is certainly more than twice the actual average life of wheels on the road in question, and would be much more than twice or even three times the average life in years, except that the average mileage per car per year has recently been very low.

An average life of eight years for car wheels would require 12½ per cent per year average renewals, against only 6.21 per cent actual renewals—a discrepancy of over one half. The constant additions of new rolling-stock which are known to have been made on the road are the only apparent cause for this effect. With such an abnormal proportion of new wheels, the proportion of failures from "old age" will be decreased, and hence that the *proportion* of failures from acute diseases, such as cracked or broken, will be abnormally increased; since in a large proportion of the wheels these are the only failures which are occurring.

This table sheds especially valuable light on the cause of sharp flanges. It will be seen that there is *twenty times* as large a proportion of wheels removed because of sharp flanges among bad wheels as good ones, and that with good makers the proportion of wheels removed for sharp flanges (2.7 per cent, and that on a very crooked road) is so small as to indicate that bad quality of the wheel itself is the leading cause of sharp flanges.

Of broken or cracked wheels, only about one quarter break in the flange or tread, and nearly two thirds of the fractures arise from the bursting strains produced by forcing the wheels on the axles.

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351. REPAIRS OF CARS.—In Table 86, page 203, the proportion of the cost of this item assignable to the effect of grades and curvature is given as some 23 per cent. Of this at least three fourths would ordinarily be assignable to the effect of grades and only one fourth to curvature. Then, proceeding exactly as in the case of engine repairs, we have $6 \times 20 = 120$ per cent of the average total cost of car repairs per mile as the extra cost due to 600° of curvature. This estimate is certainly large enough, and probably considerably too large.

An exact distribution of the cost of rolling-stock repairs to its various causes is very difficult, because the expenses are not ordinarily kept by items, but only by aggregates. Some recent statistics as to wheel wear, however (the chief and almost the only item of car repairs affected by curvature), given in Table 114, afford some valuable insight into the causes which destroy them most, and indicate that the wear from curvature is a comparatively minor element.

352. WEAR OF RAILS.—We may take the wear of good rails on curves, as an average of their whole life, at about ¼ lb. per 10,000,000 tons

per degree of curve, or certainly not more than this. Observations by the [illegible] of the New York, Pennsylvania & Ohio Railroad and some more elaborate investigations on the Pennsylvania Railroad by Dr. Charles B. Dudley, agree in indicating this, when allowance is made for the fact that the wear is not at a uniform rate during the whole life of the rail (par. 313 *et seq.*), but is perhaps, rudely speaking, only one fourth of the total during the first half of its life and three fourths during the latter half. As a consequence, as already pointed out (par. [illegible]), the wear shown by an investigation of a lot of rails of the same absolute age on different curves will apparently indicate a very much greater wear on sharp curves; but this appearance is deceptive.

The wear in tangents, then, being (as it is) about 1 lb. per 10,000,000 tons duty, the wear on a continuous 11° 20′ curve will be ½ lb. × 11⅓ = [illegible] lbs. per mile of curve, or be increased 567 per cent over the tangent wear. But this is assuming that the tangent rails are so good that they will need renewals only from the effect of abrasion, in which case rails will cost only about ⅛ ct. per train-mile.

With inferior steel rails, as formerly with iron rails, the proportionate increase of wear is very much less than this, owing simply to the fact that the tangent wear is so very much greater. The additional rail wear on curves was estimated by the writer in the first edition of this treatise—and so far as he can now judge, with very close correctness—at [illegible] per cent increase over the tangent wear on an 11° 20′ curve. The absolute amount of abrasion is much the same with all rails, iron or steel, good or bad. With rails that fail only by abrasion, therefore, the curve wear adds a large percentage to a very small total cost. With rails [illegible] the curve wear becomes a much smaller [illegible] total.

[illegible] the effect of curvature on ties has been much de[illegible] rails and will be still further and very [illegible] compared ties. Still its effect [illegible] Several years of the tie's life must be [illegible] the holding power of the spike be[illegible] of ties (par. 121) is also greater [illegible] the rail. As the rail wears by [illegible] to renew the rails prema[illegible] The effect of all these causes to[illegible] matter of fact and considerable [illegible] this respect indicates that [illegible] average life of white-oak ties on

sand or gravel ballast, imperfectly drained—the life given on curves being, if anything, too short:

On a tangent, ...	9 years.
On a 2° curve, ...	8 "
On a 6° curve, ...	7 "
On a 10° curve, ...	6 "
On a 14° to° 16° curve, . . .	5 "

From this we may conclude that the cost for ties on an 11° 20′ curve (600° per mile) is about 50 per cent greater than on a tangent, and that the increase is directly as the degree of curvature on any given distance; or, in other words, is uniform per degree, whatever the radius.

354. TRACK LABOR is, as a matter of fact, but little affected by curvature. It is an unusual thing to see sections made shorter than others on this account. If two contiguous sections are noticeably different in this respect it is not unusual to take a quarter or half a mile off one and add it to the other, but any greater difference than this is unlikely. Yet comparing the conditions which would exist on a mile of tangent and a mile of 11° 20′ curve, it might not unfairly be claimed that there would be a difference of 50 per cent in the cost of track labor; and to avoid that very objectionable result, an underestimate of the disadvantages of curvature, we may assume this, which will amply cover the facts.

355. SUMMING UP THE VARIOUS ITEMS AFFECTED BY CURVATURE, we obtain the following Table 115, giving the assumed effect on expenses of 600° of curvature.

The total cost per year per daily train of 1° of curvature given below, Table 115 (43.3 cts.), divided by the rate of interest on capital, will give the justifiable expenditure to save 1° of curvature estimated per daily train, viz.:

$$\text{At 5 per cent, ... } \frac{\$0.433}{0.05} = \$8.66.$$

$$\text{At 8 per cent, ... } \frac{0.433}{0.8} = 5.41.$$

$$\text{At 10 per cent, ... } \frac{0.433}{0.10} = 4.33.$$

And similarly for any other rate of interest; this being assumed, as heretofore, not to be a precisely accurate result, but one as exact as is either practicable or necessary to avoid serious errors.

360. A particular form of bad practice in respect to curvature, and one of the most prevalent and indefensible of the minor errors of location, is a weakness for VERY LONG TANGENTS and a readiness to spend money to secure them. A reasonably long tangent, say not less than 400 feet, is always very desirable, if not absolutely essential, in order to taper out the superelevation and afford room for proper transition curves; but beyond this there is no justification, theoretical or practical, for expending more than a very small sum to avoid any number of short and gentle curves. The difference in distance resulting from even very considerable and frequent breaks in a tangent is too trivial to be a serious consideration on lines of small traffic (although it may look as if it were considerable, especially on the ground; see Chap. XXVIII.), and the same is at least equally true of the curvature. Thus let us suppose that there is a section of a mile and a half out of one of those four- or five-mile tangents, in moderately difficult country, for which the following curved alignment may be substituted with some economy in first cost:

CURVES.	Central Angle.	Total Length of Tangents between Intersections.
1° *L* for 300 ft.	3°	
1½° *R* " 600 "	9°	2,500 ft.
2° *L* " 600 "	12°	2,500 "
2° *R* " 500 "	10°	2,000 "
2° *L* " 200 "	4°	1,100 "
Total.........	38°	8,100 ft.

Such an alternate alignment would perhaps have the effect of reducing a succession of considerable cuts and fills materially. How much does it damage the operating value of the line?

The difference in distance is as nearly as may be 23 feet in about 8350. The amount of curvature introduced is 38°. Then to an hypothetical line running 10 trains per day each way and

* NOTE TO TABLE 116.—Near the Pittsburg Station on the Pennsylvania Railroad is a curve of 219 feet radius on the main line. At a freight-house in the same city is a curve of 137.6 feet radius, around which 22 cars are pulled by one engine.

paying 8 per cent for capital the value of the difference would be—

23 feet distance at (possibly) 0.30 cts. × 10,	$69 00
38° curvature at $5.41 × 10, ...	2,055 80
Total, ...	$2,124 80

Many a tangent has been broken up improperly to effect less saving than this; but, on the other hand, a saving of 8000 to 10,000 cubic yards of excavation is enough to balance it; and if we reduce the estimated traffic by two thirds or three quarters, in all ordinary country the saving by breaking up the tangent would far more than justify doing so, even in light work, for the above figures fully represent every measurable disadvantage from a moderately curved line of that character.

Especially if the general character of the work is heavy, the caution of par. 14 becomes of vital moment on such alignment if the most careful engineer would avoid error.

TABLE 116. *

SHARPEST CURVES IN REGULAR USE ON STANDARD-GUAGE ROADS.

(Chiefly from a list published in the *Railroad Gazette* of Oct. 4, 1878.)

ROAD.	LOCALITY.	SHARPEST CURVE.	
		Radius. Ft.	Degree.
N. Y., New Haven & Hartford	Springfield, Mass	410	14°
Lehigh & Susquehanna	Upper Divisions	383	15°
" "	Stony Creek	320	18°
" "	Butler Branch	310	18° 32′
Baltimore & Ohio	Harper's Ferry, Md. side	400	14° 22′
" "	Ilchester	375	15° 20′
" "	Harper's Ferry, Va. side	300	19° 10′
" "	Y for Consolidation Engines	136	43°
Oroya Railroad	In Peru	395	14° 32′
Virginia Central	Over Rockfish Gap Tunnel	300	19° 10′
" "	" " " "	238	24° 15′
Pennsylvania Railroad tracks	Centennial Grounds	300	19° 10′
Pittsburg, Fort Wayne & Chicago	Pittsburg	246	23° 30′
Canarsie & Rockaway	Brooklyn	175	33° 15′
Brooklyn, Bath & Coney Island	"	55 to 125	....
Manhattan Elevated	New York City	90, 100, 103.5, 125, 150	63°
Petersburg, Va	U. S. Military Railway	50	....

The curve last given was thus described in a discussion, by Mr. C. L. McAlpine, of a paper by Mr. S. Whinery (Trans. Am. Soc. C. E., 1878), and is one of the most remarkable on record:

"Petersburg and Richmond, Virginia, fell into the hands of the Federal troops near the close of the war. The base of the latter for many months had been at City Point, on the James River.

"Early one morning imperative orders were received to run the trains of the United States Military Railways into Petersburg with the least possible delay. This was done by noon of the same day, under circumstances that would be most interesting, but foreign to the subject under discussion.

"This order was followed up by another—that railroad communication with Richmond should be effected at once.

"The railroad bridge at Petersburg, over the Appomattox, had been burned. No connection at that place had ever been made in peace times, and the first examinations showed that heavy excavations, etc., requiring *time* (for which the department never made allowance), *must* be made, before any reasonable connection with the Richmond line could be effected. This drove the engineer in charge into the apparently inadmissible curve adopted.

"Contrary to the advice of trackman and bridge-builders, a sharp curve was laid out, of more than one hundred degrees, with a radius of fifty feet, on what was to become the main line. The curve was on trestle-work, and the outside posts were framed eight inches longer than the inner ones. The ties were of sound white pine, three inches in thickness, and the rails were double spiked. Two guard rails were used, also double spiked.

"The locomotive engineers generally condemned the bridge and curve at first sight after completion, and a strong prejudice was created against it. But the writer selected the worst curve-following engine in the service, the 'Government,' and ordered her to make the first trial.

"Walking backwards, and in front, as this engine slowly made its way, it was easy to perceive her action on this sharp curve.

"A little pressure on the outer rail seemed to drive the wheels (both of the trucks and drivers) down on to the inner rail, and demonstrated practically what had been intended, that the trains must be passed through the curve at greater speed.

"Thereafter, when the locomotive men became accustomed to the curve, the speed through it was usually from eight to ten miles an hour.

"A very large traffic passed over this curve for months afterwards, supplying the armies of occupation in Richmond, and at other points to the southward, and no accident or trouble whatever was experienced at the place in question."

On the 4 per cent grades of the Mexican Railway, reversed curves of 150 ft. radius on temporary track around tunnels were operated by ordinary locomotives for a year or more at its first opening, and many other cases of such temporary use of very sharp curves might be adduced. All of the above curves, however, are in permanent track, although most of them are in localities where it is convenient to operate them at very slow speeds. The sharpest curves on the open road of three of the trunk lines are:

New York, Lake Erie & Western, ...	10°
Pennsylvania, ...	8°
Baltimore & Ohio, ...	9° 30′

The first of these curves is a reversed curve at Passaic, a few miles out of New York, and an enormous traffic passes over it. It could be taken out at very moderate expense, but has not proved sufficiently objectionable to make this appear worth while. The New York Central has one very sharp curve of about 14° on its main line, but in a yard where speed is slow.

Narrow-gauge roads have rarely used sharper than 24° curves in any part of the world, although a few as sharp as 30° are in use in Colorado and elsewhere.

CHAPTER IX.

RISE AND FALL.

361. THE expense of gradients, as we saw in part in Chapter VI., arises from two causes, which are totally distinct and must be kept so to form any correct estimate of their cost or of their proper adjustment. The association between them is accidental. The distinction between them is vital and fundamental.

THE FIRST of these causes is the direct cost, for wear and tear and fuel, of ascending to and descending from any given elevation, instead of running on a level; in other words, the cost of RISE AND FALL. This is the branch of the subject that we propose now to consider.

THE SECOND objection to gradients is the effect which the maximum or rather ruling grade (since the ruling grade may, owing to the effect of variations of velocity, be either greater or less than the nominal maximum of the profile) has to increase the cost of operating the entire line, however short the ruling grade itself may be, not by increasing the direct expense per train-mile, but by limiting the number of cars to a train.

362. This latter objection to gradients (i.e., to one particular gradient, the worst one on the line) is greatly more important than the former, but it has no real connection with it whatever, being different both in its nature and in its effect in detail on the operating expenses.

In fact, it is not, properly speaking, an attribute of gradients at all, except that, owing to the limitations of the locomotive engine, gradients happen to be the most usual cause which limits the weight of trains. But this is not invariably so. Sometimes curvature, and not gradients, is the limiting agent. For example, the Hudson River Railroad probably approaches the

nearest to being on a direct level throughout of any line of its length in the world, yet in laying out that line the locating engineer has freely introduced, upon slight occasion, short gradients of 0.3 to 0.5 per cent (15 to 25 ft. per mile), which could have been avoided at slight expense; and wisely so, because the unavoidably sharp curvature of the line effectually limits the weight of trains to such as is easily hauled on a considerable gradient. Up to a certain grade, therefore, curvature takes on this line the place of gradients as a limiting agent. Had the topography of the Hudson River permitted such an alignment as that of the Canada Southern Railway, for example, which has no curvature to speak of, a very great expenditure might have been justifiable to eliminate these same gradients which have [illegible] been freely and wisely introduced.

363. And if at some time in the future the locomotive engine should be so improved or such new motor discovered, as to be able to exert [illegible] power according to the need at [illegible] the cost for power were no [illegible] both grades and [illegible] them—the resulting [illegible] would disappear, and they [illegible] neither of them [illegible] disadvantages [illegible] trains.

[illegible] become the [illegible] attaches to the [illegible] taken bodily from it [illegible] possible coupling. The [illegible] however (its [illegible] might remain entirely un-

[illegible]—it might almost be [illegible] as a motive-power. [illegible] each axle of every [illegible] operating railways.

[illegible] between rise and [illegible] rise and fall bears a

closely approximate ratio to the *foot-pounds of work* required to lift a train *a* feet high, which is independent of the rate of the grade. Any new electrical or other motor might and probably would leave the cost of power per foot-pound—which is a small matter as it is—entirely unaffected. But the great objection to heavy gradients on railways as at present operated lies, not in their effect to increase the *foot-pounds of work* to be performed, but in the increase which they cause in the *pounds of tension* which the locomotive is required to exert while on them. The *pounds* of tension which the locomotive can exert being, from its construction, strictly limited, we are obliged to increase the *feet* passed over in surmounting elevations (i.e., to reduce the rate of grade) by every possible device, and at large expense, in order to enable the locomotive to pull large trains.

This lack of adaptability in the locomotive, i.e., inability to exert any pull whatever if the speed be reduced enough, or to give any speed whatever if the resistance be reduced enough, is its greatest mechanical defect. A partial remedy has been found in rack railways, etc., as noted in Chap. XI.

365. It therefore results that the cost of a ruling grade is directly as the RATE of grade and independent of its length or of the elevation surmounted, while, per contra, the cost of rise and fall is directly as the elevation surmounted, and (within moderate limits) independent of the rate.

366. This contrast alone is enough to show the radical distinction between them; but while the distinction is readily enough admitted in the abstract, it is frequently confused in practice, and such a practical confusion of these two wholly distinct objections to gradients destroys the value of any discussion or estimate of either, and forbids any clear understanding of the proper adjustment of grades; leading, on the one hand, to very erroneous theories that "undulating gradients" (in other words, mere surface roads on any convenient grade) are not seriously objectionable,—which in some cases, on some parts of a line, may be very nearly the case,—and, on the other hand, to equally mistaken expenditures to introduce as long and as nearly level grades as possible at all points of the line indiscriminately. The latter is a particularly dangerous and common

error. By trusting chiefly to one's impressions or "experience" in such matters, habit may make it a second nature to reduce all grades as much and as speedily as possible, and to stretch out the longest piece of thread which can be made to lie on the profile in fixing the grades. A thousand feet further is not far on the profile, but it often entails a considerable expense for construction to no purpose whatever. On the other hand, the contrary error—an undiscriminating readiness to use "undulating grades"—has seriously reduced the value of more miles of railway in the Western United States, perhaps, than all the other causes combined; because, unfortunately, nature has left it possible in that region to run almost from anywhere to anywhere in very nearly an air-line if we are willing to accept what are euphemistically called "moderate" grades of 25 to 75 feet per mile; instead of the dead level, or nearly that, which in many cases was equally easy to obtain by moderate deviations from some "50-mile tangent."

367. To some extent the cost of rise and fall, as well as the limiting effect of gradients, depends upon the rate of grade, for it must be divided, as respects cost and disadvantages, into three quite distinct classes, according to the grades on which it occurs.

These classes are:

A. Rise and fall on grades so light or so situated as never to require the use of brakes nor variations in the power of the engine.

B. Rise and fall on grades heavy enough to require the slight use of brakes or shutting off steam, or both, in descending, but not such as to be a serious tax upon the engine in ascending.

C. Rise and fall on maximum grades, requiring the full power of the engine in ascending, with more or less use of sand, danger of slipping drivers, and the use of brakes in descending.

To which one of these classes any given grade will belong, will depend in good part upon the general character of the line;

but as between the classes themselves there is a marked and decided difference in cost, in passing from one to the other.

In order to determine the method by which they may be correctly distinguished from each other, it will be necessary to consider now one of the most important departments of the subject of ruling or limiting gradients, as well as of rise and fall, viz.:

THE LAWS OF ACCELERATED AND RETARDED MOTION, AND THE EFFECT THEREOF ON THE MOVEMENT OF TRAINS.

368. We cannot go into the general theory of this question as fully as might be desirable, because the final results of such a discussion, which we shall need to use, will be in so simple a form that any one can use them almost mechanically. The student is urgently recommended, if not already familiar with the general laws of mechanics, to study and master the elementary principles at least of theoretical mechanics, which it requires no great labor to do. Almost any treatise, thoroughly mastered, will suffice, but Todhunter's "Mechanics for Beginners" (the title being somewhat misleading) is particularly useful for those who desire to go thoroughly into the subject, and test their knowledge by example. In this respect Todhunter's entire mathematical series are quite unequalled. A fair but in some respects deficient general idea can be obtained from Trautwine's "Pocket-Book," which may be assumed to be in the hands of every engineer. The writer knows of no treatise in which the important practical applications of these general principles which we are about to discuss are more than obscurely hinted at.

369. A railway train, or any other body, acted upon by any force or any number of forces, as gravity, the tractive power of the locomotive, friction, etc., which are for the time being uniform in their action and yet do not exactly balance and destroy each other, is under the condition technically known as uniformly accelerated or retarded motion, the laws of which are the same as for a body falling freely in a vacuum, acted upon by gravity alone. Rather, the latter also is but one particular case of a general law.

When one of the forces, as train resistance or air resistance, is not constant, but increases or decreases with the velocity, the body will not be governed by the laws of uniformly accelerated motion, but by laws much more complicated. Within moderate limits, however, and within limits sufficiently broad for our present purposes, the motion may be assumed to be uniformly accelerated or retarded without sensible error, and we shall so consider it, except where otherwise explicitly stated.

370. All energy or work communicated to any body must be employed either (1) in overcoming frictional or other resistances, or (2) stored up, so to speak, within the body, in the form of an increase of velocity. The energy so stored up is reconvertible into work at any time without loss, and its amount, for any given velocity, may be very simply determined by formula, or instantly from a table (Tables 117 and 118).

371. To determine by formula the work represented by a given velocity, or the velocity attainable by a given amount of work: It was found experimentally long since—by Galileo, at the leaning tower of Pisa—that a body falling freely toward the earth, with no opposing resistances to impede its motion (in other words, a body continually acted upon by a force equal to what we term its weight), will fall through 16.08 feet in one second of time (in the latitude of Italy or New York, 16.04 at the equator, 16.095 at London, 51° 31′ N.; 16.127 at 80° N.), and will then be moving with a velocity of twice its average velocity, or 32.16 feet per second. In the second second the velocity previously acquired will carry it through 32.16 feet, and the continuous action of the original force will carry it through an additional distance of 16.08 feet, and communicate an additional velocity of 32.16 feet per second, making the total distance fallen through in the second second 48.24, and the final velocity acquired 64.32 feet per second. By this process, which can be varied in many ways, and which was in the beginning purely empirical, the general laws have been determined which may be summarized thus:

The total time being as 1, 2, 3, 4, etc., the velocity, either average or final, will be as 1, 2, 3, 4, etc. The total spaces passed through will be as the square of the velocities, or 1, 4, 9, 16, etc., and the spaces for each time as 1, 3, 5, 7, 9, etc. The final velocity is always twice the average velocity.

The height, $= h$, through which a body must fall to acquire a velocity of v feet per second is

$$h = \frac{v^2}{2g} = \frac{v^2}{64.32},$$

or to acquire a velocity of V miles per hour; since $v = \frac{5280}{60 \times 60} V$,

$$h = \frac{\left(\frac{5280}{60 \times 60}\right)^2 V^2}{64.32} = 0.033445 V^2.$$

372. Why the constant 32.16 above noted should be precisely what it is, instead of 22.16 or 42.16, is unknown, and science does not even tend to determine it; but it is known that this constant, which is called the ACCELERATION OF GRAVITY, will vary directly with the force, if the latter be greater or less than gravity; so that with this change made, the formula is of general application to a body acted on by any uniformly accelerating force whatever.

373. From this formula Table 117 is calculated. It gives at once the velocity in miles per hour which will be acquired by a train (or any other body) falling without frictional resistance through a given vertical distance (acted on by a force equal to its weight for a given distance) and hence, conversely, the vertical distance through which momentum alone will lift the train moving at any given velocity against the force of gravity. Nothing more than this table and a general understanding of the subject is needed to solve all ordinary problems connected with location arising from variations of velocity, except for one detail, which makes Table 118 the better one to use.

TABLE 117.

HEIGHT IN VERTICAL FEET THROUGH WHICH A BODY MUST FALL TO ACQUIRE A GIVEN VELOCITY IN MILES PER HOUR,

Or the height through which the energy due to that velocity will lift the body against gravity only before it comes to rest.

Miles Per Hour.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0.......	0.00	0.03	0.13	0.30	0.54	0.84	1.20	1.64	2.14	2.71
10.......	3.34	4.05	4.82	5.65	6.55	7.52	8.56	9.67	10.84	12.07
20.......	13.38	14.75	16.19	17.69	19.26	20.90	22.61	24.38	26.22	28.13
30.......	30.10	32.14	34.25	36.42	38.66	40.97	43.34	45.78	48.29	50.87
40.......	53.51	56.22	58.99	61.84	64.75	67.72	70.77	73.88	77.05	80.30
50......	83.61	86.99	90.43	93.94	97.52	101.17	104.88	108.66	112.50	116.42

$$\text{Formula: } h = \frac{\left(\frac{5280}{60 \times 60}\right)^2 V^2 \text{ (in miles per hour)}}{64.32} = 0.033445 V^2.$$

For computations connected with the movement of trains the following Table 118 should be used.

374. The formula of par. 371 assumes that the body is in motion as a whole, but that its parts are at rest relatively to each other. In a mov-

ing train this is not so; for the wheels and axles, in addition to their forward motion, are in rapid rotation, so that additional energy is stored up within them as in so many fly-wheels. To put the same truth in another way: Each particle in the wheels and axles (except on the axis) moves more feet per second through space (albeit in a curved path) than the train as a whole, so that they necessarily have more energy stored within them.

The energy due to the rotation of the wheels and stored up in them as in a fly-wheel is usually computed separately from that which they have in common with the rest of the train, when it is computed at all; but for all purposes in connection with the motion of trains for which the one is required to be known, the other may be said to be also, and in Table 118 the two are included together. If the wheels were not in contact with the rails, but were mounted like fly-wheels within the car, they would exercise no effect upon the forward motion of the train. After the train had been brought to a stop they would continue to spin around indefinitely until stopped by their own friction; but, being in contact with the rails (or if mounted on the body of the car and connected with the wheels by gearing), they act very effectually to carry the train along just so much farther, in the same way as the rotating fly-wheel on the little toy locomotives, which almost every one has seen, causes the latter to move, being in that case the only motive-power.

375. The amount of energy in any rotating body is determined, as may be seen in any treatise on mechanics, by determining the position and velocity of a point called the centre of gyration, which is the point at which, if the whole mass of the rotating body were concentrated, any given force would communicate the same velocity of rotation as it does to the actual body. Motion in a circular or other curved path at any given linear velocity means the accumulation of the same amount of energy as if the body, as a whole, were moving in a right line at the same velocity, and if the body be both revolving and moving forward, like the wheels, the two are separate and in addition to each other.

376. The manner of determining this radius of gyration it is needless to go into in detail. According to the pattern of wheel, it will vary between 0.7 and 0.8 of the actual radius, being in car wheels nearer 0.7 and in locomotive drivers fully 0.8. Assuming a minimum radius of 0.7, it will be plain that points on that circle are rotating with a linear velocity of 0.7 times the velocity of the train, and hence that the rotative energy only of the wheels will be 0.7^2 or 0.49 —in round numbers one half that due to the forward motion of the wheels in common with the rest of the train. Really it should be a little more than this even figure for ordinary patterns of wheels, and in locomotives it is fully six-tenths.

Estimating ordinary car wheels to weigh 2¼ tons per 8-wheeled car, or 561 pounds per wheel, the ratio of the weight of the wheels to the total weight will be about—

	In a Passenger or Loaded Freight Car.	In an Empty Freight Car.	In Locomotive and Tender.
Weighing	22½ tons.	9 tons.	....
Per cent of weight of wheels	10 p. c.	25 p. c.	10 to 12½ p. c.
Making an addition to the total energy of the train of about	5 p. c.	12½ p. c.	6 to 7½ p. c.

We may say, therefore, that the rotative energy of the wheels will add about 6 per cent as a minimum to the accumulated energy or "velocity head" of the train as a whole, in the case of ordinary passenger or loaded freight trains, which with very heavily loaded cars may be a little less, but in the case of long trains of empty cars may be some 4 or 5 per cent higher. Under this assumption, assuming 6.14 per cent for ease of computation, Table 118 was computed, which is the proper one for use in all computations concerning the energy stored in trains at various velocities.

TABLE 118.

TOTAL ENERGY OF POTENTIAL LIFT IN VERTICAL FEET (OR VELOCITY HEAD) IN TRAINS MOVING AT VARIOUS VELOCITIES.

Including the Effect of the Rotative Energy of the Wheels for Passenger or Loaded Freight Trains, assumed at 6.14 per cent of the total energy. For trains of empty flat or coal cars add about 4 per cent to the quantities below, and proportionately for mixed trains.

MILES PER HOUR.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
Vel. ft.	0.00	0.04	0.14	0.32	0.57	0.89	1.28	1.74	2.27	2.88
MILES PER HOUR.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
10	3.55	3.62	3.69	3.77	3.84	3.92	3.99	4.07	4.15	4.22
11	4.30	4.38	4.46	4.54	4.62	4.70	4.79	4.87	4.95	5.03
12	5.11	5.19	5.28	5.37	5.46	5.55	5.64	5.73	5.82	5.91
13	6.00	6.09	6.19	6.28	6.38	6.47	6.57	6.67	6.76	6.86
14	6.96	7.06	7.16	7.27	7.37	7.47	7.57	7.68	7.78	7.89
15	7.99	8.10	8.21	8.32	8.43	8.54	8.65	8.76	8.87	8.98
16	9.09	9.21	9.32	9.44	9.55	9.67	9.79	9.90	10.02	10.14
17	10.26	10.39	10.51	10.64	10.76	10.88	11.01	11.13	11.26	11.38
18	11.50	11.63	11.76	11.90	12.03	12.16	12.20	12.43	12.56	12.69
19	12.82	12.96	13.09	13.23	13.37	13.51	13.64	13.78	13.92	14.06
20	14.20	14.34	14.49	14.64	14.78	14.93	15.08	15.23	15.38	15.52

Assumed average grade of rolling friction, as above, = 0.4. Then

$$\frac{14.20 \text{ (from table)}}{2.84} = 5.00 + 1.00 - 0.4 = 5.6 + 0.75 = 7.47,$$

being the percentage of the efficiency of the brakes or rate of an equivalent grade; and grade of $7.47 \times 20 = 159.4$ lbs. per ton retarding force from brakes.

2. Train 90 per cent braked; 60 miles per hour; 1014 ft. length of stop; grade, 26.4 ft. per mile (0.5 per cent) ascending.

Assumed average grade of rolling friction, as above, = 0.8.

$$\frac{127.80 \text{ (from table)}}{10.14} = 12.60 - 0.50 - 0.8 = 11.30 + 0.90 = 12.56.$$

377. THE MAGNITUDE of any force is expressed (in English) in *pounds* or some multiple.

THE WORK DONE (or which has been or can be done) by the continued application of any force is expressed in *foot-pounds*, i.e., by the force in pounds multiplied by the distance in feet through which it acts or has acted or can act. A Consolidation locomotive has a tractive force of, say, 20,000 lbs. The work done by such an engine in running a mile is $20,000 \times 5280 = 105,600,000$ foot-pounds. A HORSE-POWER is 33,000 foot-pounds per minute. If, therefore, such an engine run a mile in 4 minutes its horse-power is $\frac{105,600,000}{33,000 \times 4} = 800$ horse-power. If it run a mile in 5 minutes it is exerting a force of only $\frac{105,600,000}{33,000 \times 5} = 640$ horse-power.

If a train at a certain velocity has an average resistance of 10 pounds per ton, the power consumed by it will be 10 foot-pounds per ton per foot, or 52,800 foot-pounds per ton per mile. If, again, the resistance of brakes be added, assuming the total pressure on the brake-blocks to be equal to half the weight of train or 1000 lbs. per ton, and assuming the coefficient of friction to be at 0.16 (it is in reality very variable), the retarding force of the brakes will be $1000 \times 0.16 = 160$ lbs. per ton, and the work done per ton by the brakes (in dissipating energy) will be 160 foot-pounds per foot through which the brakes act.

378. The same amount of energy (in excess of all retarding forces) communicated from any source to any body moving in any direction will cause that body to move THROUGH SPACE with the same velocity. The DIRECTION of the motion may vary. The VELOCITY of motion will not vary, and will always be equal to that required to lift the body through the vertical height through which the body would have to fall freely in a vacuum to acquire that velocity.

FIELD NOTES REQUIRED FOR COMPUTING BRAKE TESTS.

1. *Speed* in miles per hour at instant of applying brakes.

2. *Distance run* after applying brakes, in feet.

3. *Rate of grade*, ascending or descending, in per cent, i.e., feet per station of 100 ft.

4. *Proportion of the total weight of the train to which brakes were applied.* (Except as necessary to determine this *proportion*, the total weight of the train, or the total weight on braked or unbraked wheels, is unessential, and does not enter into the computation.)

To these essential notes should preferably be added:

5. *Time of stop* in seconds (best taken with a stop-watch).

PROCESS OF COMPUTATION.

1. Take from the table the height in vertical feet corresponding to its speed, i.e., the "Vel. head." Divide it by the length of the stop in stations of 100 ft. The quotient (which will in all ordinary cases be between the extreme limits of 2.00 and 20.00) is the *equivalent grade of retardation* for a stop on a level grade.

2. To this quotient *add* the *actual* rate of grade, if descending, or *subtract* it if ascending. *Subtract* also the grade representing the average train resistance during the entire stop, which may be approximately assumed as follows:

	Miles per hour.					
Initial speed, ...	25 and less.	30	40	50	55	60
	Pounds per ton (2000 lbs.).					
Average resistance during stop, . .	8	9	10	12	14	16
	Per cent (or feet per 100).					
Equivalent grade, ...	0.4	0.45	0.5	0.6	0.7	0.8

3. The resulting sum or difference is the actual *equivalent grade of retardation*, in feet per 100: or the effect of the brakes as a whole on the train as a whole. The figures expressing this grade, as 5.00, 8.50, 12.45, express also the efficiency of the brakes upon the train as a whole, *in percentages of the total weight of the train.*

4. Divide this grade or percentage by the *per cent of the total weight of the train upon which brakes acted or were adapted, intended, or expected to act.* The quotient is the actual efficiency of the brakes upon the load carried by the braked wheels, or upon that portion thereof which it was intended to rely upon in proportioning the brakes. This quotient will always lie between the extreme limits of 25.00 and 1.00, usually between 3.00 and 14.00, and is the only one by which comparisons with different trains having differently distributed brakes can properly be made.

By formula: $\text{Grade of retardation} = \dfrac{\text{Vel. head}}{\text{Distance}} \left\{ \begin{array}{l} + \text{ rate of } \textit{descending} \text{ grade, or} \\ - \quad " \quad " \quad \textit{ascending} \quad " \end{array} \right\} -$ grade of rolling friction; and $\dfrac{\text{Grade of retardation}}{\text{p. c. of wt. of train on which brakes acted}} = \text{Efficiency of}$ brakes in per cent of weight on which they acted.

EXAMPLES.

1. Train with ¾ (75 per cent) of weight braked; 20 miles per hour; 284 ft. (2.84 stations), distance run; grade, 52.8 ft. per mile (1.0 per cent) descending.

that the force f (technically known as the grade resistance, although in descending it is not a resistance but an accelerating force) bears the same ratio to the weight that the rise in any distance does to the length ac, *measured on the slope, and not horizontally*. Practically, however, on any ordinary railway grade the horizontal distance bc is not sensibly different from the length measured along the surface of the rails ac, and hence it is customary and proper to assume $bc = ac$; whence we have, approximately,

$$\frac{f}{W} = \frac{ab}{bc};$$

or, if we let the horizontal distance $bc = 100$, and the height $ab = r =$ rate of grade or rise in 100 (whether feet or other horizontal unit, if we use the same for both vertical and horizontal), then we have

$$\frac{f}{W} = \frac{r}{100} \text{ or } f = \frac{Wr}{100}.$$

382. If, in this equation, we let $W = 2000 =$ the number of pounds in a ton, we have

$$f = 20r,$$

or THE GRADE RESISTANCE IN LBS. PER TON = RATE OF GRADE PER [illegible]. This rule should be memorized by every railroad engineer, [illegible] "Rate of grade in tenths $\times$ 2." E.g. [illegible] grade the grade resistance is 20 lbs. per ton; on a [illegible] lbs. per ton.

[illegible] it is only necessary to increase the re- [illegible] more than saying that if the rate of grade be [illegible] the resistance per ton will be $\frac{1}{100}$ ton, which is [illegible]

383. [illegible] of the error in assuming in Fig 63, that, for [illegible] the base ab may be assumed [illegible] grade resistance [illegible] shown by Table 129.

[illegible] may be considered the utmost limit of ordi- [illegible] resistance is only 0.005, or less than [illegible] grade on which the locomotive has [illegible] half of one per cent.

[illegible] the actual weight, W, Fig. 63, [illegible] the same: but for any grade [illegible] as the error, what there [illegible] grade resistance.

TABLE 119.

COMPARATIVE LENGTH PER STATION OF 100 FT. (OR OTHER UNIT) OF VARIOUS GRADES, MEASURED HORIZONTALLY AND ALONG THE SLOPE.

Giving also the percentage of excess in the computed grade resistance under the rule $f = 20r$ of par. 382.

Rise in 100. (*ab*, Fig. 63.) (= rate of grade per cent.)	Length on Slope (*ac*) for Horizontal Distance (*bc*) of 100.
1.00	100.005
2.00	100.020
3.00	100.045
4.00	100.080
5.00	100.125
6.00	100.180
7.00	100.245
8.00	100.319
9.00	100.404
10.00	100.499

NOTE.—This table likewise affords a good opportunity for testing the convenient rule elsewhere given for solving right-angled triangles of small altitude, viz.:

Diff. between hyp. and base = *ht.*^{2} ÷ *twice hyp. or base* (whichever is known).

It will be seen to be correct with these triangles to within a very minute percentage.

384. The grade which produces a longitudinal force precisely equivalent in pounds per ton (or any other unit) to the "rolling friction" of the car at any given velocity is called the GRADE OF REPOSE for that velocity, being that grade on which, if a car or train were descending, the accelerating force of gravity would just balance the resistance to motion, and hence enable it to continue in motion forever at the same speed, neither gaining nor losing velocity, which is the theoretical condition of all bodies to which a given velocity has once been communicated, according to Newton's first law of motion.

385. As the frictional resistance per ton varies with either the velocity or the length of train, the "grade of repose" will also vary with either; but these grades, as determined by Table 166, in Chap. XIII., are given in Tables 120, 180, pp. 358, 579.

386. The term "grade of repose" is ill-chosen, and originated in the mistaken idea that a grade which was heavy enough to more than equal the resistance of motion when a train was once moving, was heavy enough to start a train from a state of rest. In reality, a grade several times heavier is necessary, and this latter grade only can properly be called a "grade of repose." But the ill-chosen term is still the common one, as is likewise, unhappily, the erroneous idea in which it originated. Otherwise, probably, there would be fewer stations on limiting grades.

387. When a railway train descending a grade, or any other falling body, is acted upon by an accelerating force which remains uniform,—like the traction of a locomotive or gravity,—in opposition to a retarding force which increases with the velocity,—like the resistance of a train,—the velocity of motion will continue to increase until the retarding force becomes equal to the accelerating, and thereafter the body will continue in motion indefinitely at a uniform velocity. The net resultant of all the forces acting is then zero, and consequently the body continues indefinitely in motion at an unvarying velocity, as theory requires.

388. This statement should be read over until its meaning is fully grasped. A railway train in motion at a uniform velocity is acted on in one sense by two forces, but in a truer sense by no force. The frictional and other resistances and the traction of the locomotive act upon and destroy each other within the body, without either acting upon the body itself, except to produce internal stress. Such a body is therefore one of the nearest examples in practical mechanics of Newton's abstract conception of a body moving on indefinitely *in vacuo* from original impulse, without gain or loss of enérgy, as do the heavenly bodies.

389. Under such conditions ANY NEW FORCE—whether accelerating or retarding, like a change in the rate of grade or in the tractive force of the locomotive—will act upon the body precisely as if no other forces existed to act upon it; i.e., THE WHOLE of the new force, undiminished by frictional or other losses, will act upon the body to vary its velocity, and will vary it precisely as theory requires. This fact bears with it important consequences.

To illustrate this interconvertibility of work and velocity: Let us assume any body, as a car, weighing 20,000 pounds to have fallen freely (i.e., without, or in excess of, the loss by friction) 16.08 feet. It would then have $20{,}000 \times 16.08 = 321{,}600$ foot-pounds of work stored up in it, and would be moving through space with the precise velocity of 32.16 feet per second or about 21 miles per hour.

If, instead of having fallen vertically, either gravity, or the tension on the draw-bar, or any other force, had been communicating to that same car body continuously a force of 20 pounds (or one pound per ton in excess of all resistance), the car would have to move through a distance of $\frac{321{,}600}{20} = 16{,}080$ feet to store up within itself 321,600 foot-pounds, and hence to acquire the same velocity that it acquires when falling freely through space, or, when acted upon (in any direction) by a force equal to its weight, in 16.08 ft.

390. This velocity once acquired, the corresponding amount of energy stored in the car may be expended in any one of the following ways:

First. It may (theoretically) by proper mechanical appliances be made to lift

the body vertically through a height of 16.08 feet, which it will do in one second of time, and bring it to a state of rest.

391. *Secondly.* It may be made to lift the body up an inclined plane A, A', A'', A''', Fig. 64, as on a grade of any rate, against the action of gravity. In

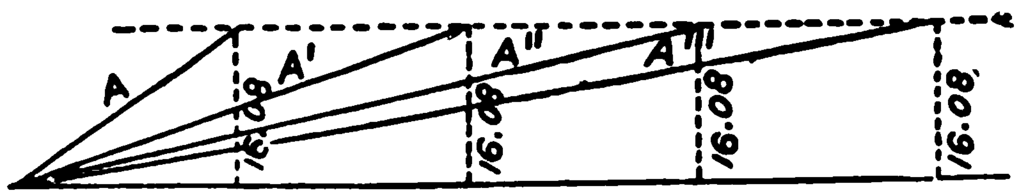


FIG. 64.

this case, if there be no other resisting force but gravity, the body will rise through the same vertical height in all cases before coming to rest. The distance run and the time occupied in the ascent will alone vary. The vertical elevation surmounted will not vary. But as there is a resisting forçe (rolling friction) which is so much per foot run, these conditions do not precisely obtain in practice.

392. *Thirdly.* It may be made to propel the body on a level against the resistance of axle and rolling friction. If the natural resistance to motion be 7 lbs. per ton, or 70 lbs. for the car, its accumulated energy of 321,600 foot-pounds will continue it in motion for a distance of $\frac{321.600}{70} = 4594$ feet before it comes to a state of rest.

This "rolling friction," so called, of 7 or a pounds per ton of 2000 pounds is precisely equivalent in its mechanical effects to a grade rising 7 or a feet in 2000, or to the "grade of repose" before explained (par. 384).

It follows, therefore, that any given grade other than a level is equivalent in its mechanical effect upon the train, if it be an ascending grade, to the actual rate of grade *plus* the grade of repose; and if it be a descending grade, to the actual rate *minus* the grade of repose.

393. *Fourthly.* The accumulated energy of the car may be sooner exhausted by calling in the action of brakes in addition to the resistances of gravity and rolling friction. If there be brake-blocks on half the wheels only (which has until recently been the general custom for freight service), and the pressure on them be equal to the load on the wheel, which is somewhat more than that which the ordinary brake leverage is intended to give (modern experiments indicate that not more than two thirds of the load on the wheels is a safe pressure), and if the coefficient of friction between brake and wheel be $\frac{1}{6}$ which is about an average (it varies in reality from $\frac{1}{4}$ to $\frac{1}{8}$) then the retarding forces on the car will be—

Brakes, $\frac{20,000}{2} \times 1 \times \frac{1}{6}$	$= 1,667$ lbs.
Normal rolling friction as above $=$	70 "
Resistance of grade if on a level $=$	0 "

Total resistances on a level $= 1,737$ lbs. or 173.7 lbs. per

ton of 2000 lbs. The car will, consequently, come to a state of rest on a level grade in a distance of $\frac{321,600 \text{ ft.-lbs.}}{1737 \text{ lbs.}} = 185$ feet, supposing the brakes to be instantly applied and with their full force, neither of which is very likely to be the case.

If the car be on an ascending or descending grade instead of on a level the + or − resistance of the grade is to be included among the resistances. If the car stood on a descending grade of $\frac{173.7}{2000} = 8.69$ per cent, or 458 ft. per mile, it would continue in motion forever at the same velocity even with brakes set. This has repeatedly been proven practically on 8 and 10 per cent grades.

If there were 10 cars in the train, moving at the velocity of 32.16 feet per second, and only one of them, as above, had brakes set, then we should have—

Brake resistance,	1,667 lbs.
Rolling friction 70 × 10,	700 "
Total resistances on a level,	2,367 lbs.

and $\frac{3,216,000 \text{ ft.-lbs.}}{2,367 \text{ lbs.}} = 1359$ feet, as the distance in which the train would come to a state of rest.*

394. *Fifthly.* The accumulated energy of the car may be made to act conjointly with the full power of the locomotive to carry it over a particularly difficult gradient. If the full power of the locomotive is just sufficient to carry the car or train over any grade of *a* per cent, Figs. 65 to 67, the energy of momentum will carry the car or train up a grade which rises in all 16.08 feet higher; whether that rise be by a uniform excess of rate, as in Fig. 65, or in a local excess at certain points, as in Figs. 66 and 67.

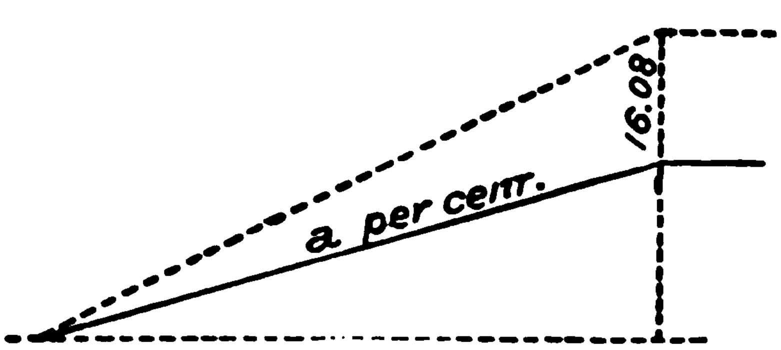


FIG. 65.

In this case the office of the locomotive is simply to neutralize all grades and rolling resistances due to the *a* per cent grade. All extraneous forces thus neutralizing and destroying each other, the *vis viva* of the body lifts it through the additional rise of 16.08 feet, precisely as, and to the full extent that, theory requires; but if the power of the locomotive is completely used up on the *a* per

* This calculation is not quite correct, because the wheels, in addition to their linear velocity in common with the remainder of the car, have an energy of rotation which adds some 6 per cent to the total *vis viva* of the car, as noted in par. 374 *et seq.* Nor should computations of this kind be ordinarily made as above, but by the "velocity-heads" given in Table 118, which include the rotative energy of the wheels.

cent grade, the train will come to a state of rest at the summit, which is 16.08 feet higher, in spite of the exertion of the full power of the locomotive and the aid of the stored energy jointly. Grades so operated are called **MOMENTUM GRADES.**

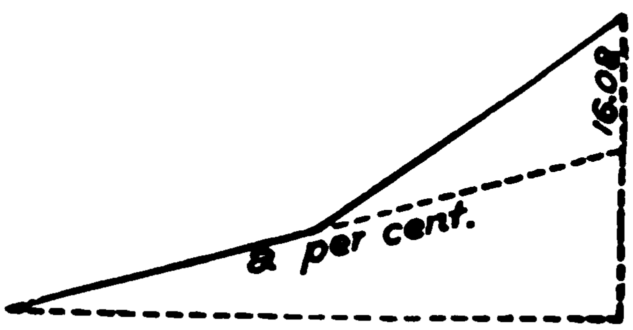


FIG. 66.

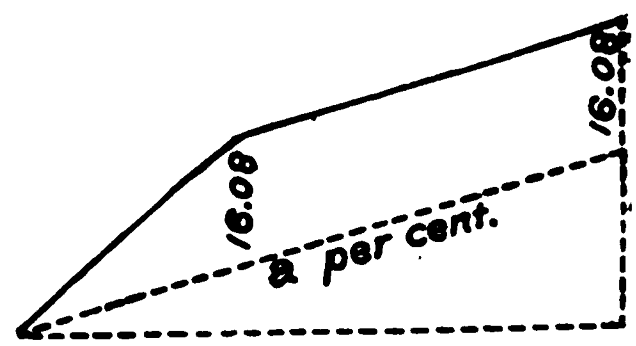


FIG. 67.

395. *Sixthly.* The accumulated energy in the car may, in theory, be made by proper mechanical appliances to compress a spring, drive a pile, or do any other kind of work whatsoever capable of measurement in foot-pounds. If a spring required a force of 10,000 pounds to compress it one inch and its resistance continued uniform, then the energy of the car body would compress the spring $\frac{321,600}{10,000} = 32.16$ inches. A perfectly elastic body, to which a spring approximates, would immediately give back this energy to the car and repel it with equal velocity. A perfectly inelastic body, such as a bank of earth, which required a pressure of 10,000 pounds to enable a body of the size of the car to penetrate it one inch, would (if the resistance continued uniform) be likewise penetrated 32.16 inches, and would not repel the body. The energy would be converted into heat.

A pile which opposed a static resistance to motion of 100,000 pounds would in theory be driven $\frac{321,600}{100,000} = 3.21$ feet, or 322 similar piles would be driven 0.01 feet, if the resistance to motion were uniform, which it is not.

396. A rod of iron of one square inch section, which would require a load of 26,000,000 pounds to extend it to double its length if its resistance to extension continued uniform,—i.e., whose *modulus of elasticity* was 26,000,000, —would sustain a force of only some 50,000 pounds without rupture, and say 25,000 pounds without producing a permanent set. Therefore, if those effects are to be avoided, the stress on the rod must at no time exceed that limit; and since, if the car is to be stopped by the rod, 321,600 foot-pounds are to be absorbed, by reaction against a force beginning at zero (since the slightest force will extend the bar somewhat) and gradually increasing to 50,000 or 25,000 pounds respectively, we have

$$\frac{321,600}{50,000 \div 2} = 128.64 \text{ feet}$$

as the length which the rod would have to stretch to avoid the rupture, and

$$\frac{321,600}{25,000 \div 2} = 257.28 \text{ feet}$$

as the length which the rod would have to stretch to avoid exceeding the elastic limit. But (assuming uniformity of elasticity) the rod can only stretch in any case the $\frac{50.000}{26,000,000}$ part of its length $\left(\frac{1}{1,300}\right)$ without rupture, and only half that without permanent set.

Therefore, to avoid these effects and yet enable the bar to do (or use up) the requisite amount of work in stopping the car, it would have to be

$128.64 \times 1300 = 167,232$ ft. long to avoid the rupture, and
$257.28 \times 2600 = 668,928$ ft. long to avoid permanent set;—

which are rather long bars. The consequences to the car body also we will not consider, but the example will serve to illustrate the laws of the mutual convertibility of energy or work, and velocity.

397. From this ready interconvertibility of velocity and work results the undoubted fact—too little considered by engineers—that train resistance, in practical operation (i.e., as measured by the tension on the draw-bar of the locomotive, or graphically recorded by a dynamometer) bears no very close and apparent relationship to what may be called the DEAD resistance, as determined by adding the nominal grade resistance to a certain rolling friction, without paying any regard to the effect of differences of velocity. This is well understood by all those who have had occasion to deal with dynamometer experiments, and is the greatest difficulty in deducing valuable results from such experiments. It is also well understood in a practical way by locomotive engineers, who appreciate the great advantage of a "run at a hill" and the disadvantage of a stop on it.

398. Now the object before the engineer in laying out a railway is, obviously, to lay out his line so that THE DEMAND ON THE LOCOMOTIVE, and not the absolute grade resistance (which latter is in itself a thing of no moment), shall be as nearly uniform as possible, under the conditions which actually exist in the daily routine of operation. If, at a certain point, the velocity of the trains has certainly to be increased, in addition to overcoming the normal grade and rolling resistances, the gradient is in effect increased at that point. If at a certain other point velocity can safely be acquired before reaching it and then

surrendered, the grades are in effect reduced. The VIRTUAL or equivalent profile, including these effects of velocity, is what the engineer should study, and should consider as the true profile of the line for operating purposes, as distinguished from the nominal grades shown by the levels and the plotted profiles.

399. The two are widely different even in freight service, and much more so in passenger service. Thus, when a train starts out from a station it has to acquire a certain velocity as speedily as possible—say 15, 20, or 40 miles per hour; giving which velocity is mechanically equivalent to lifting the train vertically (see Table 118) 7.99, 14.20, or 56.80 feet. This rise, divided by the distance in which the velocity is or must be attained, gives a grade which is in effect an addition to the actual grade. Thus, if there be a station at *A*, Fig. 68, on a nominally level grade, and it be necessary to acquire a velocity of 21.3 miles per hour (being nearly the "velocity-head," as per Table 118, for 16.08 feet), and it be necessary to acquire that velocity in at most 2000 feet, the "virtual" grade is that shown by the solid line in Fig. 68, or $\frac{16.08}{20} = .804$ per cent.

If the train then strikes a down grade, no change in the strain upon the draw-bar necessarily takes place, nor probably will take place, if the grade be short or the speed high. More probably, the same steam-power and tension on the draw-bar will be continuously exerted, and the excess of power over that consumed by the resistances will be stored up in the train as velocity, to be surrendered in part on the next up grade; and so on indefinitely.

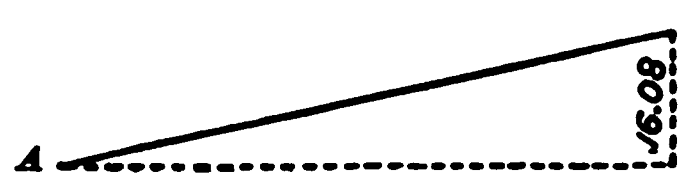


FIG. 68.

In fast passenger service, with a sufficiently good track and alignment to admit of high speed, the amount of energy required to cause even slight modifications of speed between stations is so great that the effect of undulations of gradients, even of considerable size, is almost wholly eliminated.

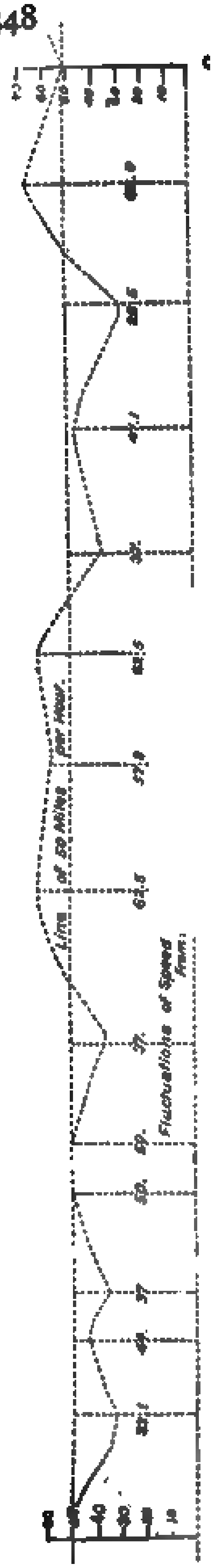


FIG. 69.—EFFECT OF VARIATIONS OF VELOCITY TO A LEVEL VIRTUAL PROFILE.
The upper dotted diagram shows the variations of velocity.

400. Thus, Fig. 69 is an example from actual practice of a very bad undulatory profile (for freight service), which not only may be, but actually is, operated by express passenger trains almost as a level grade.

To determine in practice how velocity affects the operation of this or any other similar profile is a problem of the simplest possible character. We require nothing to aid us but Table 118. Thus, let us suppose that an express passenger train approaches the point *A*, Fig. 69, as it actually does, at a velocity of about 50 miles per hour, the point being situated at the foot of a long gentle incline. This velocity being given, in order to run without a stop to the point *B*, a distance of about eleven miles, no further burden is laid upon the locomotive than to furnish the power which is necessary to keep the train moving on the "equivalent" maximum grade, which in this case is a dead level, despite the fact that the profile maximum is 1 per cent or 52.8 ft. per mile.

The process of determining in advance whether it will be possible to operate this undulating grade as a level gradient in this manner, and what the fluctuations of velocity must be to do it, is as follows:

401. The train at the point *A*, moving (by assumption) at 50 miles per hour, has sufficient vis

viva or "velocity-head" (Table 118) to lift it through 88.75 feet vertically before coming to a state of rest. In running to *b*, it makes a rise of 130 − 80 = 50 feet, and if the engine is to do only the work due to a level grade all the work of lifting the train through this 50 feet must be done from the energy stored as velocity, and there will consequently be left in the train, on reaching *b*, only 88.75 − 50 = 38.75 vertical feet of "head," which corresponds (Table 118) to 33 + miles per hour. The particular grade, and hence the horizontal distance, between *A* and *b* makes no difference, because the engine, if it is to operate the grade as a level, furnishes the power to overcome the frictional resistances on a level, and no more; and these alone are affected by the horizontal distances.

From *b* to *c* the train descends 30 feet. Therefore, the engine being supposed to continuously exert the same amount of force to overcome the frictional resistances, all the additional accelerating force due to the descending grade will be communicated to the train in the form of velocity, and at the foot of the grade, at *c*, the train will be moving with the velocity due to 38.75 + 30 = 68.75 vertical feet, which (Table 118) is 44 miles per hour.

From *c* to *d* there is a vertical rise of 20 feet, and consequently the train will be moving at *d* at the speed due to 68.75 − 20 = 48.75 feet, or (Table 118) 37 + miles per hour.

402. So the undulations of speed continue, as shown by figures and the dotted diagram, until on reaching the point *B*, which is neither higher nor lower than the initial point *A*, the train is found to be moving with the same velocity as at *a*, or 50 miles per hour. Whether this will be the case at any point we can determine at once, without tracing up the intermediate velocities, simply from its relative level compared with *A*.

Thus, the highest point on the stretch is at elevation 140, or 60 feet above *A*. The train here, consequently, will have only the velocity due to 88.75 − 60 = 28.75 vertical feet, or nearly 28¼ miles per hour. The lowest point is the point *n*, which is 70 feet below *A*, and the velocity at that point will consequently be that due to 88.75 + 70 = 158.75 vertical feet, or 66.9 miles per hour.

403. Now if we had a dynamometer record of the tension on the draw-bar during such a run as this (which the writer has made many times over that identical piece of track at approximately the assumed velocities) we should find it absolutely uniform and unvarying, without any appreciable trace or evidence in the recorded strains that there were any undulations in grade or deviations from a perfect level on the stretch passed over. If we were to stand and watch any coupling of the train

we should be led to the same conclusion. Assuming the vertical curves connecting the grades to have been properly put in, there would be no "slack" at any time, nor crowding of one car upon another; but, on the contrary, there would be a continuous and substantially uniform tension on every draw-bar, whether going up hill or down, and the motion of the train would be as steady as if the grade were in fact level, as to all intents and purposes it is—AT THAT VELOCITY. At slower velocities, or with intervening stops, or with very high summits, the conditions are widely different.

404. To determine the effect of all these and similar facts in advance for any piece of track and any assumed speeds, we have only to construct, with the assistance of Table 118, what may be termed the equivalent or VIRTUAL PROFILE, which is the actual profile so modified as to include these effects of probable or admissible variations of velocity. Thus at *A*, Fig. 69 or 70, moving at 50 miles per hour, the train is in the same con

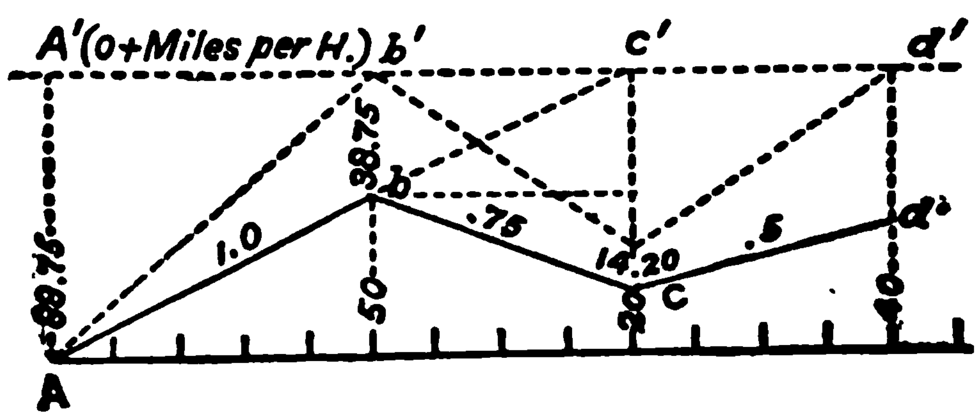


FIG. 70.

dition mechanically, as respects demands upon the motive-power, as if it were at *A'*, Fig. 70, 88.75 feet higher, moving at 0+ miles per hour. In either case it would arrive at the point *b'*, on a level with *A'*, at a velocity of 0+ miles per hour. As, however, it has only to rise 50 feet to *b*, it will, on arriving at *b*, still retain a velocity which will lift it through 38.75 vertical feet, and consequently the point for the equivalent profile is at *b'* 38.75 feet above *b*. To have the equivalent profile continue a level line, its altitude above *c* at *c'* must be 68.75, and the train, consequently, must be moving at *c* at 44 miles per hour. As this is an admissible passenger velocity, to operate the line *ac* as a virtual level at passenger speed is not impossible.

405. If, at the point *c*, it were necessary to slow up to a velocity, say, of 20 miles per hour, to pass through a town or for sharp curvature, or any other reason, this level virtual profile could not be maintained. What the equivalent profile would actually be equivalent to, must be determined by laying off above *c* the vertical altitude due to a velocity

of 20 miles per hour, or 14.20 feet. We then find that the equivalent profile becomes a sharp descent to *c*,—requiring the excessive use of brakes,—and an equally sharp ascent to *d'*: thus showing that it is practically impossible to resume the original velocity at *d*.

406. To determine what velocity we might obtain at *d*: Determine by computation, or from experience elsewhere, what is the maximum grade, *p*, Fig. 71, up which the full power of the engine could keep the train moving at 20 miles per hour, which will be a pretty stiff grade. The difference, *dd''*, Fig. 71, between the elevation which the train might attain on such grade and that which it actually has to attain at *d* will, if the engine does so exert its full power between *c* and *d*, be communicated to the train in the form of velocity, and it will be moving at *d* with the velocity due to 14.20 + *dd''* feet. If the equivalent grade were 2 per cent, or 105.6 feet per mile, instead of the actual grade of 0.5 per cent mile, the value of *dd''* would be 30 feet, and the train would be moving at *d* with the velocity due to 14.20 + 30 = 44.20 feet = 35.3 miles per hour. The point at which it will be mechanically possible for the train to entirely recover from the effect of a check or stop at *c* may be determined with equal simplicity (assuming that the train resistance did not, as it would, increase with speed) by prolonging the 2 per cent equivalent grade *cd''* until it intersects at *p* the level equivalent grade for the run without a stop. At that point the traction of the engine may be reduced to that due to a level grade and the run continued as before, as shown in Fig. 69.

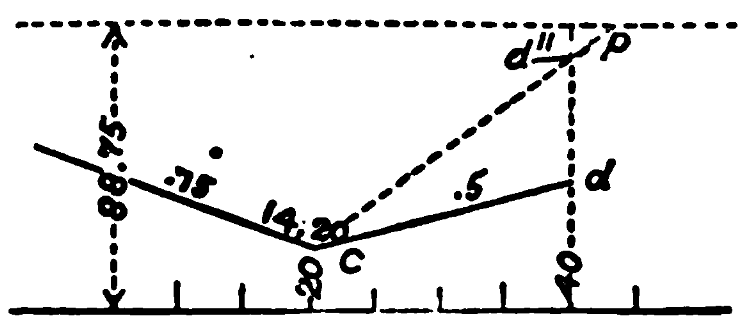


FIG. 71.

407. In this simple manner, it will be evident, an equivalent profile—which for all operating purposes is THE profile, and which is consequently the only one which the engineer should consider in laying out the line—may be constructed almost by inspection, assisted by Table 118, for any grade or section of line whatever, and for any speed or variations of speed whatever. Such an equivalent profile, if constructed for high-speed trains, will bear little or no resemblance to the actual profile; and even at low freight speeds it will be very seriously modified, and widely different in appearance from the actual profile. At points where a stop or a slackening of speed occurs the equivalent grade may be very much higher than the actual. At other points where

considerable velocity at the foot of grades is probable and admissible it will be very much lower.

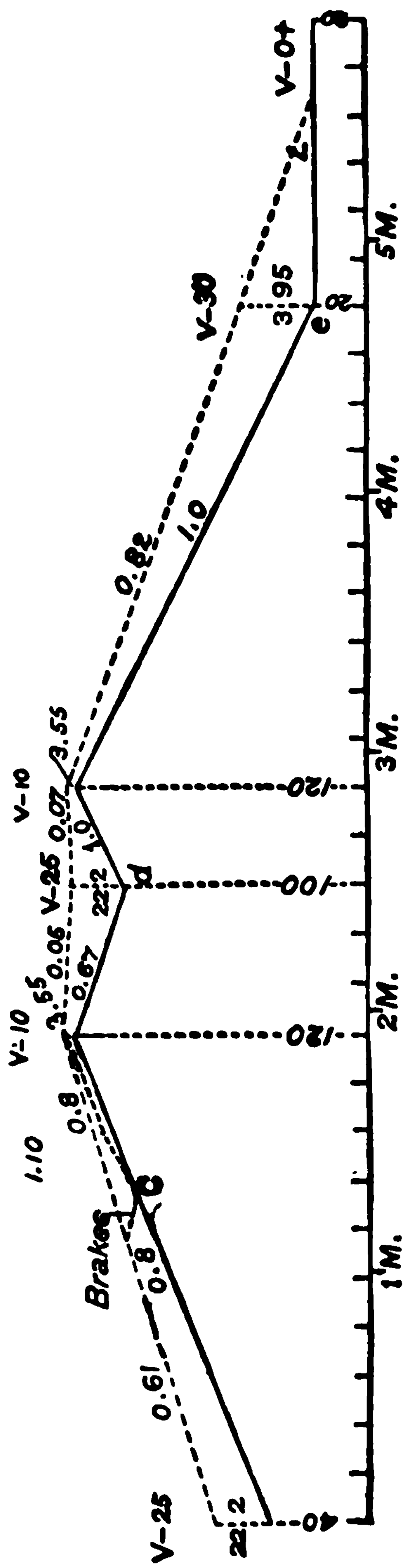


FIG. 72.—AN ACTUAL AND VIRTUAL PROFILE.

In only one respect is such a profile liable to be deceptive. The profile itself demands no allowances, but the hauling power of an engine is materially greater in making a start from what it is at speeds above 10 or 15 miles per hour, at which latter speeds or higher it is not possible ordinarily to utilize the full adhesion of the locomotive, for reasons given in Chapter XI. and XIII. Therefore a higher virtual grade at stopping points only is not necessarily a limiting gradient.

408. Fig. 72 is a representation of a virtual and actual profile, constructed in the above manner, for an assumed maximum freight speed of 25 miles per hour. We have only to take each governing point in succession; determine for each what is the actual, probable, necessary, or safe velocity at that point; lay off vertically above it the vertical feet to which this velocity is equivalent, as given in Table 118; and connect the points thus fixed by right lines. This gives the equivalent and for all operating purposes the actual profile, except that the varying train resistance at various speeds must be remembered, and likewise the greater adhesive power of the locomotive when starting and using sand.

409. Thus at *c*, where a stop is necessary, the velocity will be zero, and the virtual and actual profiles will coincide. The grades approaching this position on each side are necessarily much heavier in the virtual than in the actual profile. At other points, as at the depression *d*, the velocity will be considerable, and the approaching grades on each side are

on the virtual profile very much reduced by that fact. At still other points, as at the foot of the long grade *e*, the velocity of approach may be considerable, and yet the grade so long that this velocity has but a slight effect in reducing the virtual grade. If there were a station or a pretty heavy minor grade near the foot of the long grade, as is apt to be the case, no surplus velocity at all could be assumed, and the virtual and actual profile would again coincide.

For a further example from practice of the effect of varying velocity to modify gradients, and of the deceptive indications of the power of engines obtained by neglecting it, see the close of Chapter XX.

410. It will be evident that, in practical work, a virtual profile need not be constructed for the entire length of the line, but only at points where it is likely to make an important difference. On long stretches of level or minor gradients we need feel no anxiety, unless at stopping points. On long stretches of maximum grade we know that we must accept the actual as the virtual grade. In such a sag as that at *d*, Fig. 72, it is plain that virtual profile will differ importantly, but it is unnecessary to draw it as in the cut. Granting our assumed safe velocity in the hollow *d*, of 25 miles per hour (vel.-head, by Table 118, 22.2 ft.), and the assumed velocity of 10 miles per hour (vel.-head, 3.55 ft.) on the summits on each side, the assumed difference of velocity in effect *makes a fill* at *d* of $22.2 - 3.5 = 16.7$ feet. We have therefore merely to lay off vertically 16.7 feet above *d* and connect the point thus fixed and the actual summits by a dotted grade line, and we obtain the same virtual profile as that shown in Fig. 72, but 3.55 feet lower, so as to touch the actual grade line at the summit; and so at any other point.

411. The danger in using such a process as this as a basis for laying out grades is solely one common to most engineering and other work—bad judgment as to the practical possibilities and necessities. Thus, a stop may be required where one is not anticipated, or a velocity may be assumed which, owing to curvature or other cause, may not be practicable or expedient. The possible use of sand in starting or at particular points, or the varying power of the locomotive, may be forgotten, or a speed may be assumed at summits so low as to leave an insufficient margin for head winds and similar contingencies. The lowest speed that can properly be assumed at a summit, as a general rule, in view of these contingencies, is about 10 miles per hour

for freight trains and 20 miles per hour for passenger trains. Even that is leaving very little margin, for when a train has fallen below a speed of 10 miles per hour it requires very little to stall it.

Nevertheless with reasonable care and skill it is a simple matter to construct such a profile and save the consequences of the vague and rash guesses as to the effect of "taking a run" at grades, which are sometimes made, when the effect of momentum is considered at all.

This most important caution should be remembered, however: WITH THE VIRTUAL PROFILE ONCE PROPERLY CONSTRUCTED, NO FURTHER LIBERTIES CAN BE TAKEN WITH IT. The maximum virtual grade represents PRECISELY the power of the engine; and whether the virtual gradient be 100 feet or 100 miles long, it is equally decisive of the power of the engine, except as the latter may itself vary.

412. It will be evident from the preceding discussion that rise and fall has the most serious effect on slow freight service, and will in all cases become inadmissible for such service considerably before it becomes of serious moment for passenger trains. Such an undulation of profile as is shown at *d*, Fig. 72, for example, produces hardly any measurable effect upon the speed of a fast passenger train, simply causing an undulation of a few miles per hour in ordinary passenger speed (say from 50 to 55 miles per hour), which is hardly perceptible to the senses. In this rise and fall is unlike curvature, for the latter (if the grades have been properly compensated) is most objectionable for high-speed service.

413. The extremely important effect which even very moderate fluctuations of velocity may have to modify nominal grades, even for slow freight trains, is illustrated in Fig. 73. According to the profile this is a 0.8 per cent (42 feet per mile) maximum grade, and even allowing somewhat for the effect of "momentum" it would be very apt to be classed as a 0.6 grade. In reality, the 0.8 grade at the top of the hill may be one mile long, and it can still be operated as a virtual 0.4 grade (21 feet

per mile) if we may count with certainty on approaching the foot of the hill at a speed of 23¾ We shall still be able to turn the hill with a velocity of nearly 10 miles per hour, our highest intermediate velocity being 28 miles per hour.

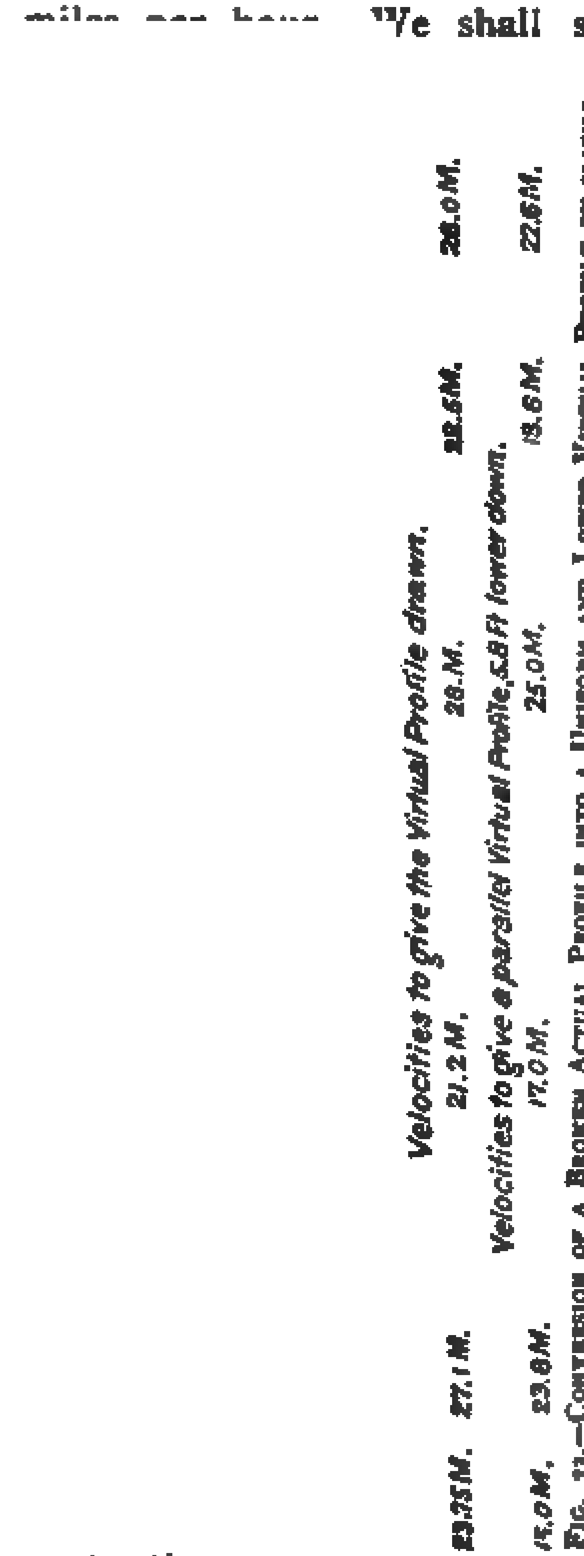


FIG. 73.—CONVERSION OF A BROKEN ACTUAL PROFILE INTO A UNIFORM AND LOWER VIRTUAL PROFILE BY SLIGHT DIFFERENCES OF VELOCITY.

If we cannot count on a higher velocity than 15 miles per hour at the foot of the hill, whether because of curvature, a station, or bad grades, we cannot quite do this. W shall have only 18 instead o 24 vertical feet of "head" the train at elevation 120, 3 which we must have at summit to avoid danger of st ing. As we use up 0.4 fee head for each station of 0.8 g the 0.8 grade, at the to the hill cannot be longer $\frac{18-3}{0.4} = \frac{15}{0.4} = 37.5$ stations, entire grade is to be operate virtual 0.4.

Such undulations are of tremely desirable for econom or to make an otherwise impo cation feasible. Let us theref mine their exact effect on service and the consequent lin practice; since if these limits unnecessary injury may be done to the line. In Fig. 73, for example, the virtual gradient shown is a reasonable one because at no point does it reduce the speed very low, but if the points at elevations 60 and 110 were ten or fifteen feet higher it would no longer be so.

The introduction of close couplers is now (1890) rapidly reducing the need for very long vertical curves.

SAFE LIMITS OF UNDULATIONS OF GRADE.

414. We will suppose a train of 40 cars, say 1300 feet long and weighing 1600 tons, to be moving with a uniform velocity of 15 miles per hour (22 feet per second) toward station 100, Fig. 74. The pull of the locomotive is perhaps 16,000 lbs., being in any case precisely that required to move the train at 15 miles per hour on a long 0.2 grade.

It has been already stated (pars. 399, 403) that so long as the steam-power of the locomotive is unvaried the relative motion of the train and

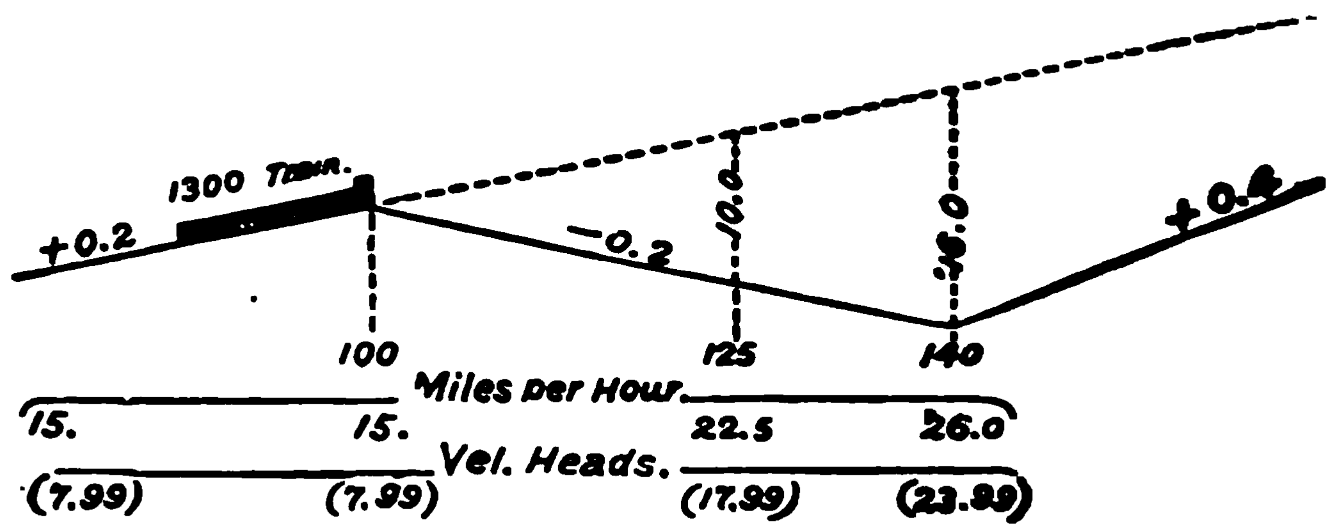


FIG. 74.

the tension on each draw-bar will be practically uniform and unvarying, whatever the variation of grade, the change in resistance taking the form of increased or decreased velocity. The only time when the tension on the draw-bar is not absolutely fixed and unvarying is in passing from one grade to another, and this occurs as follows:

415. As the engine passes over station 100, Fig. 74, continuously exerting the same steam-power, the change in the rate of grade (from + 0.2 to − 0.2) makes a difference of 8 lbs. per net ton of its weight, or, say, $8 \times 62.5 = 500$ lbs. in all, in its pull on the draw-bar, thus increasing its pull on the train for the moment from 16,000 to 16,500 lbs., or about 3 per cent. This increased traction will immediately begin to make the train move faster, and as some of it must be absorbed in making the engine itself move faster, not all of it will be transmitted backward to the train.

Three seconds afterwards, two other cars will have passed over station 100, and will increase the traction on the draw-bars behind them by some 320 lbs. more. This increase of tractive force, likewise, having no extra resistance to use it up, will take the form of an increase in velocity.

So as each car in succession passes over the break of grade the accel-

erating force gradually increases from zero (as the engine approaches station 100) to 8 lbs. per ton of weight of the whole train, when the entire train has finally passed over the apex.

416. The instant that this occurs the tension on the draw-bars will be precisely the same as before throughout, viz., that due to the work of the engine only, and will be employed in the same manner—in overcoming the normal train resistance on a grade of + 0.2 at the original velocity; while the extra accelerating force from the change of grade will be acting upon the train independently to communicate velocity, precisely as if it were descending the same plane without resistance and with no other force acting.

The final velocity at stations 125 and 140 will be precisely the same as if it had fallen freely through a height equal to—not the actual difference of level between 100 and 140—but through a vertical height equal to the drop in the actual—0.2 grade from the dotted + 0.2 grade, on which, by assumption, the locomotive was exerting just enough power to keep the train moving at 15 miles per hour.

What will be the velocity of motion, then, at 125? Computing it as before, we have—

The original velocity of 15 miles per hour is equivalent to a fall through space of (see Table 118)	7.99 feet.
The dip in the grade is	10.00 "
Hence the train at 125 will have the velocity "due" to a free fall of	17.99 "

which by Table 118 will be 22.5 miles per hour.

This is an entirely safe and unobjectionable velocity. At station 140 the "dip" is 16 feet instead of 10.0 feet, and the velocity acquired is 16.0 + 7.99 = 23.99 vert. feet = a velocity of 26.0 miles per hour, which may be claimed to approach the utmost limit of expediency for freight service.

Had the dip been 20 feet, the velocity acquired would have been about 28.1 miles per hour. A dip of 20 feet may therefore be considered about the maximum which it is permissible to ride over in freight service without shutting off steam, on good track and with favorable alignment.

417. These velocities would actually be somewhat less than the figures given, owing to the fact (1) that the CENTRE OF GRAVITY of the train does not rise quite as high or fall quite as low as the highest or lowest point of the track, and (2) that the resistance of the train in-

creases with the velocity (see Table 120 and Chap. XIII.), whereas we have assumed it to be constant; but as the difference is of no great moment in the details we are now considering, and as the neglect of it tends to safety, it is not here considered.

TABLE 120.

APPROXIMATE GRADES OF REPOSE FOR VARIOUS TRAINS (AS DETERMINED IN TABLE 166). SEE ALSO TABLE 180.

VELOCITY. MILES PER HOUR.	FREIGHT TRAINS OF—		PASSENGER TRAINS OF—		APPROXIMATE GENERAL AVERAGE.	
	Twenty Cars.	Fifty Cars.	Four Cars.	Twelve Cars.	Grade Per Cent.	Feet Per Mile.
10......	0.30	0.28	0.34	0.27	0.30	16.84
15......	0.36	0.33	0.40	0.34	0.35	19.48
20......	0.46	0.40	0.52	0.42	0.40	21.12
25......	0.58	0.48	0.69	0.53	0.50	26.40
30......	0.73	0.59	0.88	0.65	0.65	36.32
40	1.10	0.90	1.38	0.98	1.00	52.80
50......	....	....	2.02	1.39	1.50	79.20
60......	....	....	2.81	1.89	2.25	118.80
70......	....	....	3.74	2.49	3.00	168.40

The resistance in pounds per ton is given by multiplying the above by 20.

418. Now, what takes place in the hollow at 140, when the engine begins to ascend? Here, if anywhere, is the point of danger, and here is in fact a very great danger, the precise nature and limits of which should be determined. The danger arises from the fact that in the hollow of a grade, where the head of the train is on an up grade and the rear of the train on a down grade, there is liable to be a momentary crowding together of the train.

This liability occurs only when the head and rear of the train are on different grades. We have just seen (pars. 415, 416) that when the whole train is on the same grade, however great its rate of ascent or descent, the tension on the draw-bars will remain the same, being that arising from the traction of the locomotive, and the additional energy communicated to or taken from the train by the grade will take the form of an increase or decrease of velocity, which is uniform throughout the train because the grade is uniform.

419. In the hollow of a grade this is not so, and hence arises the tendency for the rear of the train to run up against the front when passing such points under certain conditions, taking all the "slack" out of

the train and bringing the draw-bars into more or less compression. The next instant, when the hollow is passed and the uniform grade (whatever it may be) is struck, the normal condition of tension throughout the train returns, but returns with a jerk; for with the present awkward style of couplings the difference in length of a train in tension or compression is very considerable. The "slack" varies from 4 to 6 inches or more per car, according to the degree of force with which the springs are compressed and extended, so that a train of 60 or 80 empty cars may shorten as much as 30 to 40 ft. The jerk, when this slack is "taken out," is exceedingly apt to break the train in two, and it is at such hollows in grades that most of such breakages occur.

420. The reality of the danger may be illustrated by a literally truthful anecdote: In the old days of iron rails, some thirty-five years ago, when derailments were much more frequent and more easily caused than now, a certain especially poor road was having very frequent derailments, so that each conductor was having derailments every few days. One of the older conductors was singularly exempt from such accidents, for which no reason appeared. In answer to repeated questions, he at last confessed that he "always kept his caboose brake set up a little." This was contrary to orders, but it had the practical effect of keeping the draw-bars always in tension, and at the cost of a slight waste of power prevented the more serious danger.

Such crowding together is dangerous, not only for the quick jerk which must almost inevitably follow it, but because it tends to crowd the cars out sidewise against one or the other rail, and so produce irregularity of motion, causing the wheels to hunt, as it were, even more zealously than they ordinarily do, for the first defect by which they may escape from the track. Especially on curves this is very dangerous.

421. The philosophy of trains breaking in two is simply this: At the top of the grade the steam is partially shut off and the brakes put on slightly; but before reaching the foot of the grade the brakes are almost always let off, and the train strikes the foot of the ascent "full of slack." A careful engineman will then let on steam gently, and all will be well. The more careless will "pull out" with a jerk, and, if he be careless enough, he will be almost certain to break a link or pull out a draw-head, for such parts can hardly be made strong enough (at least in the present fashion) to resist a too sudden exertion of the power of the engine. To a great extent the number of such accidents is entirely in the hands of the engineer. It has not unfrequently happened that, when the employés were annoyed by an increase of train or other cause, the feeling of annoyance has taken the form of a jerky fashion of pulling out the throttle, which has resulted in an alarming increase in such accidents and ter-

rified a doubting or inexperienced superintendent. So, too, the introduction of heavier engines has had and will almost certainly have dangerous consequences, —for a time,—partly because the enginemen are really inexperienced in handling such powerful machines and partly from a secret willingness to throw discredit upon them.

422. We will consider the mechanical reasons why a very slight setting up of brakes on a rear car should reduce these dangers, and how—as that remedy is objectionable as a regular reliance—it also can be safely dispensed with in passing sags.

A train of cars coupled together may be considered as, mechanically, a single solid body. All solid bodies have more or less elasticity, and alter their dimensions under exterior force applied to certain parts only. A train has more than usual longitudinal elasticity: that is all.

The motion of such a body, as respects the action of gravity, is the same as if its mass were concentrated at its centre of gravity.

423. The centre of gravity of such a train does not descend into the apex of the hollow in Fig. 74 or 75 (assuming such sharp intersections of

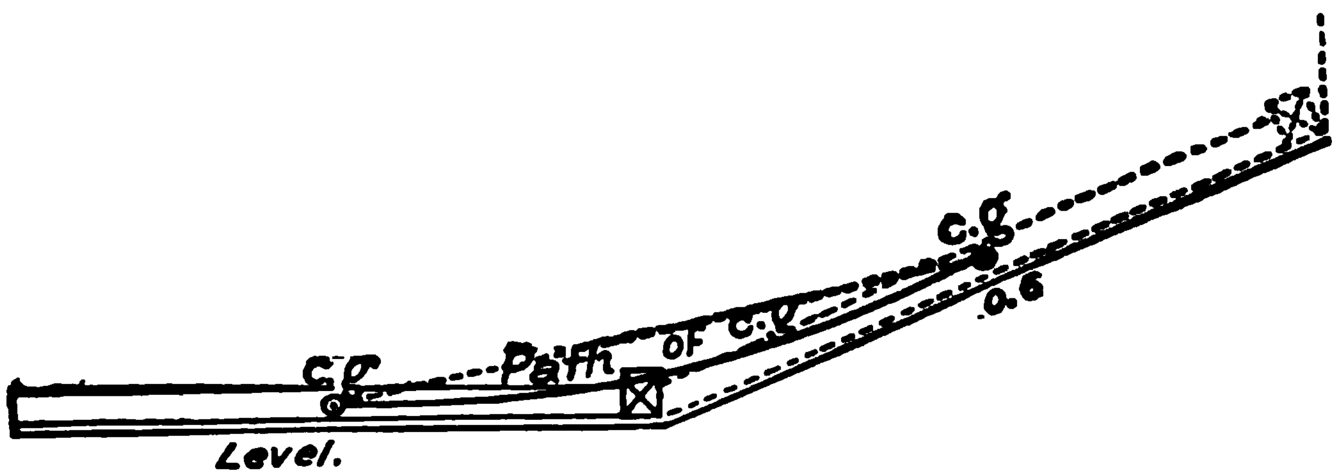


FIG. 75.

grade to exist in practice), although each individual car does. Its path lies—for simple geometrical reasons which the student may be assumed either to understand or to take for granted—at a uniform distance above a circular arc or parabola (according to the assumptions made) tangent to the two grades at the points *c.g.*, one half train-length from the apex. In Fig. 75 we assume, as the simplest case, that a level grade intersects an 0.6 per cent ascent, instead of a − 0.2 and + 0.4 grade in Fig. 74. The results we shall reach are not essentially varied, whatever the rates of the separate grades, if their angle of intersection is the same.

Let us assume for the moment the train in Fig. 75 to be exerting within itself just energy enough to balance its own resistances, so that it is in the theoretical condition of a body moving *in vacuo* without either

gaining or losing velocity, and moving at, say, 26 miles per hour, equal to a "velocity-head" (Table 118) of 23.99 feet. For simplicity we will assume the train to be 1200 feet long and to weigh uniformly one ton per foot, and we will assume it to consist of only 8, 12, or more very long cars instead of some 40, as it probably would.

424. Under these conditions, when the train has reached the position indicated by the black line *OC* in Fig. 76, with the rear car just past the apex *O*, its centre of gravity *B* will be precisely $6.00 \times 0.6 = 3.6$ feet higher than at *A*, and the train as a whole will have surrendered an amount of energy and of velocity corresponding to that height. The centre of

Level. O C

FIG. 76.

gravity will have moved in the arc *AOB*, and the velocity with which the train as a whole is moving at any point *O* or *B* is given with absolute precision bv substracting the ordinates to the curve from the base-line *AA'* from the initial "velocity-head," as is done in Fig. 76. At *B* the velocity will be only 24.0 miles per hour.

With the train in this position, each car considered separately would have surrendered the energy and velocity represented by the successively diminishing ordinates *aa'*, and if the train were, as assumed, a body moving through space from original impulse without resistance or communicated force, the inevitable effect of such conditions would be to produce a uniform compression throughout the body at all the points *aa'* (each rear particle pressing against that in front of it) whenever the path of the body were deflected upward, however slightly.

425. But the train, although as a whole it is in the condition stated, yet internally to itself is in very different condition. A strong accelerating force (the engine) is acting in front at *C*, a strong retarding force (say 10 lbs. per ton) throughout the rear of the body. The two counteract and destroy each other, their net resultant being zero; but in so doing they produce, or tend to produce, a state of tension throughout the train.

What is required is, not that this tension shall not be reduced in passing changes of grade, but that it shall not be exchanged in any part of the train (or only in a very small part) for a state of compression. A train may be, as respects its couplings, in three conditions:

1. *In tension*, its normal condition, which, whether greater or less, will only extend the springs a little more or less, but make no material difference in the whole length of the train.

2. *In neither tension nor compression*, the two adjacent cars tending for the moment to move with the same velocity, so that no force of any kind is communicated from one to the other. This condition can only be momentary.

3. *In compression*, the cars behind crowding upon those in front.

In the transition from the first to this last condition lies the whole danger. So long as we do not pass the second (which is more properly merely a line of demarcation between the first and third) we are safe.

426. This we shall avoid if the rear car (or cars), where the tension is least, nowhere itself tends to move faster than the train as a whole is moving at the same moment, during the period of transition from one grade to another, Figs. 75, 76, or 78.

The rear car, when travelling on a grade of any rate, as *a*, *b*, or *c*, Fig. 77, has a certain frictional resistance which will make it of itself, without exterior assistance, surrender velocity as if it were moving on the dotted grade without friction, instead of on the actual grade with friction.

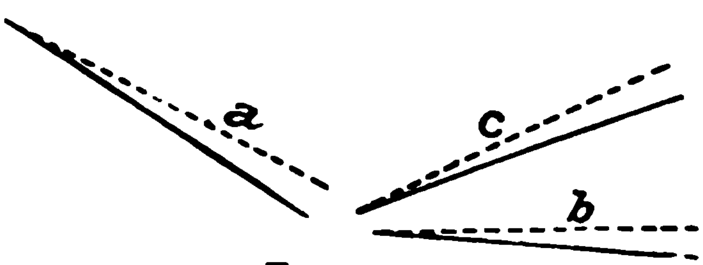


FIG. 77.

The difference between the dotted and actual grade is the so-called "grade of repose," marked *g* in Fig. 78. By even a slight application of brakes this grade of repose may be very greatly increased.

Since the train as a whole, then, is moving, mechanically, without friction, and surrendering velocity at the same rate as if its mass were concentrated at its centre of gravity and moving in the path thereof (*A B*, Figs. 76 and 78), at each point in the passage from *A* to *B* the train as a whole is surrendering velocity ***at the rate due to the grade on which the centre of gravity is for the moment moving*** in its path ***AB***. The steepest point on this curve is at the tangent point *B*, at which same

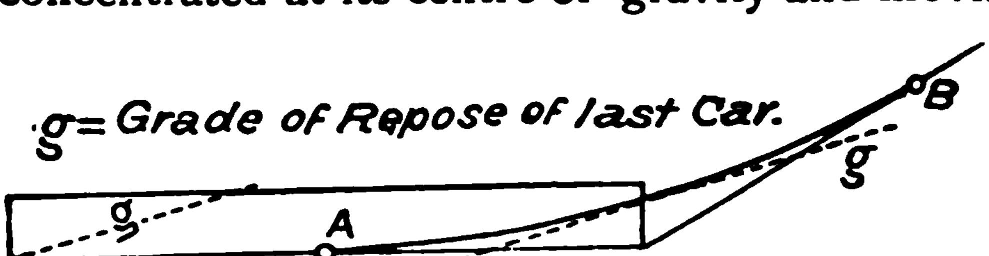


FIG. 78.

instant the rear car of the train itself strikes the up grade at O, and encounters the same retarding resistance as the rest of the train, so that the danger of its crowding up on it is then past.

427. By comparison of the conditions just stated for the last car and the whole train we deduce this simple rule:

TO OBVIATE ALL DANGER OF THE REAR PORTION OF THE TRAIN CROWDING UPON THE CARS IN FRONT, WITHOUT THE USE OF BRAKES, AT ANY SAG IN A GRADE LINE:

The rate of the grade on which the head of the train stands must in no case exceed that on which the rear of the train stands by more than the "grade of repose" of the last car. Otherwise the latter will crowd up upon the train.

428. The grade of repose may be increased for the time being above the normal (1) by applying brakes, and (2) by the engineman "pulling out" or beginning to exert more force upon the train at or quite near to the apex O. In the latter case, until the train has acquired a velocity corresponding to the new tractive force, the "grade of repose" of the rear car, or its resistance to moving with the train, will be considerably greater. The first of these remedies is objectionable as a regular reliance, and the second is too uncertain. Therefore the rule above may be considered one which it is desirable to adhere to strictly whenever possible.

429. Since the conclusions reached above depend on the DIFFERENCES in the rate of grade (see Figs. 77 and 78), it is obvious that they apply alike to all hollows in grade lines, whether both be ascending, both descending, or one descending and one ascending. To see this more clearly (which should be almost self-evident), tip Fig. 78 in various directions so as to correspond to all the conditions of practice. It will be obvious that although the changes in the absolute velocity of the train and every part of it will be greatly modified, yet that the relation of the motion of the rear car to the whole train will not be modified.

FIG. 79.

FIG. 80.

430. We see in what has preceded the urgent reasons why the use of long and easy vertical curves in the hollows of grade lines should never be neglected. The conditions are entirely different in a salient or rising angle in a grade-line like Fig. 79 and in a hollow like Fig. 80. In passing over the former there is only a

momentary increase in the normal tension. If too sudden, this is objectionable, so that vertical curves should be used in all cases; but it is the REVERSAL of strain in a hollow which is particularly objectionable, and for them the rule—The change in rate of grade in a train-length should never exceed the grade of repose of the last car—should be strictly adhered to when the cost of doing so is not too great.

431. From this it follows that the longer the train and the lower the grade of repose the easier should be the vertical curve, and *vice versa*. As the grade of repose increases with the velocity, it is evident that short trains at high speed, like passenger trains, are in little danger of any such effect, and that to obviate it altogether the longest possible train and the lowest possible resistance for the last car or cars should be assumed.

The lowest probable resistance for the rear of the train at any such point is about 6 lbs. per ton. Dynamometer tests of freight trains show, indeed, average resistances of 3½ to 4 lbs. in frequent instances, but the speed is likely to be high at the particular localities in question, and there is, moreover, a certain atmospheric resistance from suction at the rear of the train (which may be estimated, by analogy, from experiments on a small scale, at about half as much per square foot as that at the head of the train) which will increase the resistance of the rear cars somewhat above the rest of the train. Curve resistance, if uncompensated (and still more when compensated, in descending a grade), may affect the question either way, according to its location. Grade resistance, as we have seen, does not in itself affect the question in the slightest. The difference between the grades at the rear and head of the train alone concerns us.

432. The utmost length of train will depend on the ruling grade of the road. An empty-car train will have about twice the length of a loaded train; but empty-car trains are unusual, their rolling friction is higher, and the phenomenon is not so objectionable that it may not in occasional instances be permitted, especially as it can be avoided by brakes, or "pulling out," if desired. A 35- or 40-car train will be, say, 1200 ft. long, and this may not unreasonably be taken as an average maximum. On heavy-grade lines a shorter assumed length of train may suffice, and on low-grade lines the trains may be much longer.

433. Assuming 1200 ft. (12 stations) length of train, and 6 lbs. per ton (0.3 grade) for the resistance of the rear car or cars, we have the rule—

of speed, we have in Table 121 the maximum velocity which sags of various depths will give to the train.

TABLE 121.

EFFECT OF SAGS OF VARIOUS DEPTHS BELOW A CONTINUOUS GRADE-LINE AND HAVING THE FORM OF EITHER FIG. 81 OR FIG. 82 TO MODIFY THE SPEED OF TRAINS.

(Computed by the aid of Table 118, as explained in par. 400 *et seq.*)

GREATEST DEPTH OF SAG IN FEET.	VEL.-HEAD IN TRAIN AT LOWEST POINT OF SAG FOR SPEEDS OF APPROACH IN MILES PER HOUR OF—			MAXIMUM SPEED IN BOTTOM OF SAG FOR SPEED OF APPROACH IN MILES PER HOUR OF—		
	10	15	20	10	15	20
None....	3.55	7.99	14.20	10.	15.	20.
5.......	8.55	12.99	19.20	15.5	19.1	23.2
10.......	13.55	17.99	24.20	19.5	22.5	26.1
15......	18.55	22.99	29.20	22.9	25.4	28.7
20.......	23.55	27.99	34.20	25.8	28.1	31.0
25.......	28.55	32.99	39.20	28.3	30.5	33.2
30.......	33.55	37.99	44.20	30.8	32.7	35.3

This table assumes that the train is approaching at a uniform speed, and that the locomotive continues to exert the same uniform power in passing the sag. The original velocity will then be resumed after passing it.

If there is an excess of accelerating or retarding force in approaching the sag, both the speed in the bottom of the sag and the speed after passing it will be correspondingly higher or lower than the speed of approach, but the table will not be essentially modified.

The manner of computing Table 121 should be carefully studied. It will be seen how little the speed of approach affects the resulting speed at the bottom of a sag in grade-line of any considerable depth. Twice the speed of approach, 20 miles per hour instead of 10, increases the speed in the hollow only some 15 per cent, or 4½ miles per hour. It will also be seen how comparatively slight is the effect of increased depth of sag. A 10-ft. sag increases 10 miles per hour to 20, but it takes 20 ft. more, or a 30 ft. sag in all, to increase the 20 miles per hour to 30. At a speed of approach of 20 miles per hour a 10-ft. sag increases the speed 6.1 miles per hour; the next 10 ft. (20 ft. in all) only 4.9 miles per hour, and the next 10 ft. only 4.3 miles per hour.

439. The table likewise shows in part (for fuller explanation see Chap. XVIII.) why a very slight break upwards from a long continuous grade-line is so very much more injurious than even a considerable drop below it. Sags even of 30 ft. will not produce an absolutely dangerous speed, but a rise of even 3½ ft. above a grade-line will bring a train mov-

ing at 10 miles per hour to a stop, or a train moving at 15 miles per hour to a speed of 11.2 miles per hour.

440. The highest freight-train speed which can be regarded as reasonably safe and practical at favorable points is about 30 miles per hour. Such speeds are ordinarily far less objectionable on long straight grades than on undulating grades, for the reason that the true objection to high freight speeds (within reason) is not the speed itself, but abrupt alterations of speed. With long and easy vertical curves (usually wanting), and with breaks of grade so designed that their depth will not give a dangerous maximum speed if they are operated as virtual continuous grades, by making no change in the work done by the locomotive but permitting its excess of work to take the form of velocity, speeds of 30 miles per hour for the moment only on good alignment cannot be considered as in the least objectionable, and are very common in present practice, and likely to become more so. (See par. 444.)

If we assume 30 miles per hour as a maximum speed at certain favorably situated points where considerable speed is desirable, it results (see Table 121) that sags of 20 or even 30 ft. from a grade-line, according to the speed of approach, may be operated as a virtual continuous grade.

441. We therefore conclude that, as a general rule, but with a number of modifying special conditions, a sag of not exceeding 20 ft. in vertical depth from the main grade-line, if eased off by a long and easy vertical curve in the hollow, will not require any slacking up or variation in steam-power, and that, if it does not, it is entirely innocuous, except for the greater wear and tear which may result from the higher speed. That expense we will estimate in par. 452 *et seq.*

442. *If the sag be deeper than 20 ft.*, and sometimes if it be considerably less than 20 ft., we have a more objectionable class of rise and fall (Class B, pars. 367 and 451). It will then be necessary either to put on brakes (which is really the best practice) or to merely shut off steam and "pull out" again at the foot of the grade, which is the too common practice.

It is in this latter kind of sags, especially if they have no adequate apology for a vertical curve, that most of the draw-heads are pulled out and trains broken in two, in the way explained in par. 418–421. In part this is avoidable by care in running. Nevertheless, with the greatest practicable care, it is not possible to prevent frequent serious jerks to trains in sags of considerable depth, which will sometimes break them

in two. Such sags, therefore, become more and more objectionable as they increase in depth, even when it is not necessary to use any brakes.

443. *The point at which it certainly becomes necessary to apply brakes,* and consequently the point at which the cost of rise and fall is materially increased (Class C, pars. 367 and 451), varies in part with the rate of grade, and may be determined as follows:

The grades of repose for various speeds, i.e., the grades on which the accelerating force of gravity just suffices of itself to keep the train in motion at the given speed without assistance from the engine and without either gain or loss of velocity, are about as given in Table 120, page 358.

It follows from Table 120, that if the admissible limit of speed on any part of the line be given, any grade, however long, *on a rate not exceeding the grade of repose for that speed,* may be of indefinite length without ever requiring the use of brakes, because all that is necessary is to shut off steam at the top of the grade *A*, Fig. 83; when the train, in descending the grade, will of itself either acquire or lose velocity until it attains

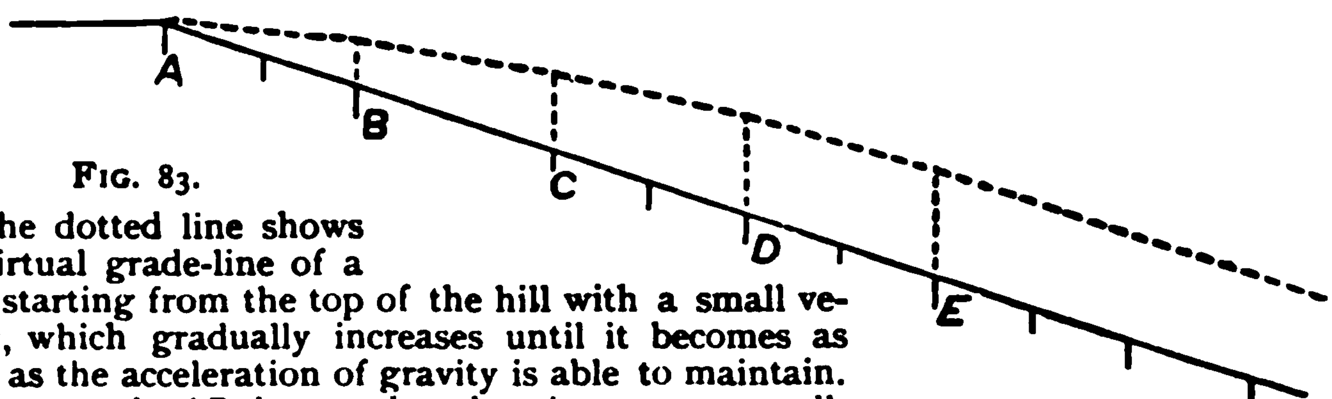


FIG. 83.

The dotted line shows the virtual grade-line of a train starting from the top of the hill with a small velocity, which gradually increases until it becomes as great as the acceleration of gravity is able to maintain. On the stretch *AB* the speed and resistance are small, and the ordinate *B* represents the vertical energy stored in the train as velocity. On the next stretch the resistance is higher, because of the higher speed, but there is still an excess of acceleration. So with the next stretch; but as the resistance grows higher and higher with each increase of velocity there necessarily comes a point where the resistance and acceleration balance each other, as given in Table 120.

the velocity at which the accelerating force precisely balances the rolling resistance. This grade will be seen to be very high for fast passenger-train speeds, so that there can rarely or never be necessity for the use of brakes on descending grades of less than 1 per cent (52.8 ft. per mile) in ordinary passenger service, merely to avoid excessive speed due to the gradients themselves. Usually, however, heavy gradients are accompanied by heavy curvature, which latter will often necessitate on long grades a rate of speed but little higher than the freight maximum.

444. The customary speed in freight service shows a steady tendency to increase at points where velocity is of assistance in hauling heavy trains. It is of course greatly affected by the character of the line as to

curvature, but the idea formerly prevalent that the most economical speed for freight trains is a very slow one has been pretty thoroughly exploded, both by theory, practice, and experiment. Experiments by Mr. P. H. Dudley on the Lake Shore & Michigan Southern Railway have shown directly that "with long and heavy freight trains it required less fuel with the same engine to run trains at 18 to 20 miles per hour than at 10 to 12 miles per hour." * This result—as to the substantial correctness of which there is little room for doubt—is not due to the actual resistances to motion being any lower, or as low, at the higher speed, but to the joint action of the following causes:

1. To the saving of power at undulations of grades, in the manner heretofore discussed in this chapter, the extra velocity serving as a reservoir of power and so preventing waste thereof.

2. To the less time of exposure of the locomotive to radiation—a saving, in all probability, of very great importance. (See pars. 344 *et al.*)

3. To the less time for radiation from the interior surface of a cylinder into the exhaust steam; also a very important source of loss.

On the other hand, evidence presented in Chapter XIII. makes it at least doubtful if the resistance is more than a pound or two per ton greater.

445. Whatever may be the cause, the expediency and economy of increasing freight-train speeds, on fair alignment, up to 20 and even (at points) 30 miles per hour is very generally recognized and acted on by the more prominent managing officers. This tendency will probably be greatly strengthened in the near future by (1) the general adoption of some form of freight-train brake and of a more durable and stronger coupler, and by (2) the increase in average car-load and consequent decrease in number of freight cars per train, with the natural attendant increase of care in the construction of freight cars. On lines using the "speed gauge" the usual maximum speed specified is 22 miles per hour, a rate in all probability which at some points on some lines has been expensively low, and would have been still more so except that the grades at stations are usually the *de-facto* limiting grades, and not those between stations.

446. It will therefore be safe in all cases to assume a maximum

* Trans. Am. Soc. C. E., Oct. 1876. The explanation there given by Mr. Dudley, that at the higher speeds "the locomotive seems to produce its power more economically by using the steam expansively to a greater extent than at slow speeds" would seem to be certainly incorrect, except as the less time for internal radiation may be supposed to be referred to.

freight-train speed of about 22 to 25 miles per hour on long grades, corresponding to a grade of repose of something under 0.5 per cent, or 26.4 feet per mile; and this, under favorable circumstances, for important ends, may be assumed to be increased to nearly 30 miles per hour, corresponding to a degree of repose of something over 0.6 per cent, or 32 feet per mile. On grades not exceeding these limits rise and fall on grades of any length will not be likely to require the use of brakes, or to endanger objectionable "slack" in the train, with the most moderate care in running.

447. The point at which a grade on rates exceeding these limits becomes so long that the use of brakes will become necessary is readily determined as follows:

Let AB, Fig. 84, be such a grade and AB' be the average grade of repose while attaining the assumed admissible velocity, say 0.4 per cent, for a

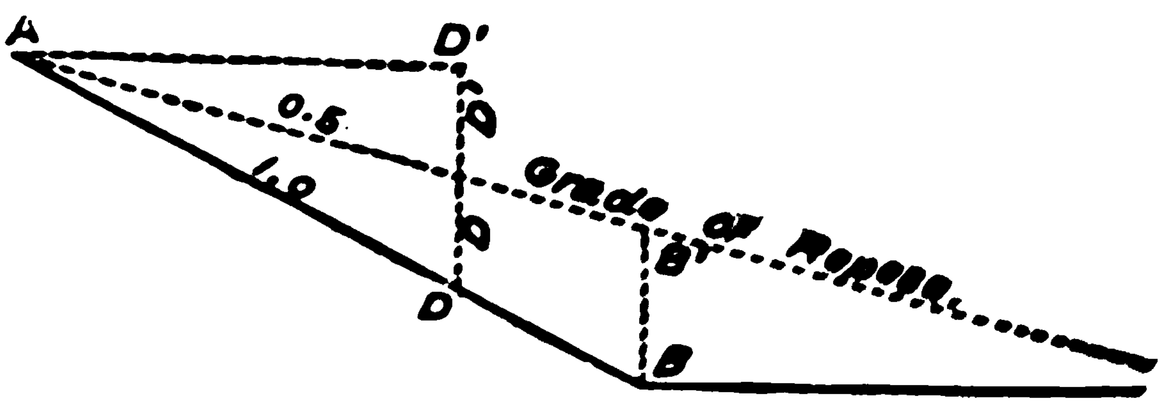


FIG. 84.

maximum velocity of 25 miles per hour, or 0.5 per cent for 30 miles per hour. Let the lowest velocity at which it is necessary, expedient, or probable that trains will approach A be also determined. It will depend on the character of the line back of A. If A be at the foot of a long grade, no lower velocity than the maximum admissible could safely be assumed, and the application of brakes would be immediately necessary on reaching A. If A were a station the initial velocity would be 0. It is desirable that the velocity should be as low as possible, but as engineers do not always pay close attention to little matters of economy such as saving the use of brakes—especially [illegible] time—it should not be taken too low. Let us suppose it to be 10 or 15 miles per hour; then we have

Initial velocity at A	10 miles per hour.	15 miles per hour
Corresponding velocity-head	3.55 ft.	7.99 ft.
Corresponding velocity-head at maximum velocity of 25 miles per hour	22.20 "	22.20 "
Difference	18.65 "	14.21 "

which latter is the vertical distance D, Fig. 84, which the grade will have to fall *below the grade of repose* before the train will acquire the maximum admissible velocity.

This being given, it is a simple matter to compute the horizontal distance AD' and the corresponding vertical fall $D + D'$. In the above example, the excess of the actual grade over the assumed 0.4 grade of repose being 0.6 per cent, we find $D + D'$ to be $\frac{18.65}{0.6} = 31.1$ stations for an initial speed of 10 miles per hour and $\frac{14.21}{0.6} = 23.7$ stations for an initial speed of 15 miles per hour. In this manner we may construct Table 122.

448. Any grade, at any given rate whatever, which does not exceed in length and vertical rise the limits of Table 122 can be operated in the routine of freight service without the use of brakes (the cost of such rise and fall being, consequently, very much less) provided that there be no excessive curvature or other special cause near the foot of the grade to require especially low speed at that point. Ordinary curvature, with a

TABLE 122.

DISTANCE WITHIN WHICH THE VELOCITY OF TRAINS DESCENDING VARIOUS GRADES WITHOUT STEAM OR USE OF BRAKES WILL EXCEED THE LIMITS OF 25 AND 30 MILES PER HOUR, STARTING WITH VARIOUS INITIAL VELOCITIES.

Rate of Grade.		Admissible Maximum Velocity of 25 Miles Per Hour.				Admissible Maximum Velocity of 30 Miles Per Hour.			
		Initial Velocity at Top of Grade, in Miles Per Hour.				Initial Velocity at Top of Grade, in Miles Per Hour.			
Per Cent.	Less Grade of Repose.	0 +	10	15	20	0 +	10	15	20
0.4	0.0	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite
0.5	0.1	222.0	186.5	142.1	80.0	"	"	"	"
0.6	0.2	111.0	93.2	71.0	40.0	319.5	284.0	239.6	177.5
0.7	0.3	74.0	62.2	47.4	26.7	159.7	142.0	119.8	88.8
0.8	0.4	55.5	46.6	35.5	20.0	106.5	94.7	79.9	59.2
0.9	0.5	44.4	37.3	28.4	16.0	79.9	71.0	59.9	44.4
1.0	0.6	37.0	32.2	23.7	13.3	63.9	56.8	47.9	35.5
1.5	1.1	20.2	17.0	12.9	7.3	32.0	28.4	24.0	17.7
2.0	1.6	13.9	11.7	8.9	5.0	21.3	18.9	16.0	11.8
3.0	2.6	8.5	7.2	5.5	3.1	12.8	11.4	9.6	7.1

TABLE 122.—*Continued.*

TOTAL VERTICAL FALL IN FEET FROM TOP OF GRADE TO POINT WHERE THE ADMISSIBLE MAXIMUM VELOCITY IS ATTAINED, AS ABOVE.

0.4	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite	Infinite
0.5	111.0	93.2	71.0	40.0	"	"	"	"
0.6	66.6	55.9	42.6	24.0	191.7	170.4	143.8	106.5
0.7	51.8	43.5	33.2	18.7	111.8	99.4	83.9	62.2
0.8	44.4	37.3	28.4	16.0	85.2	75.8	64.0	47.4
0.9	40.0	33.6	25.5	14.4	72.0	63.9	54.0	40.0
1.0	37.0	32.2	23.7	13.3	63.9	56.8	47.9	35.5
1.5	30.3	25.5	19.4	10.9	48.0	42.6	36.0	26.6
2.0	27.8	23.4	17.8	10.0	42.6	37.8	32.0	23.6
3.0	25.5	21.6	16.5	9.3	38.4	34.2	28.8	21.3

Computed as follows:

At speed of..........	0	10	15	20	......	......	......	.... .
Vel.-head..........	0.00	3.55	7.99	14.20	0.00	3.55	7.99	14.20
Do. at 25 (and 30) m. p.h.	22.20	22.20	22.20	22.20	31.95	31.95	31.95	31.95
Difference..........	22.20	18.65	14.21	8.00	31.95	28.40	23.96	17.75
Assumed average grade of repose..........	.....	.....	......	.40	......	......	......	.50

Then the actual rate of grade, less the grade of repose, gives the fall per station which goes to increase the velocity, and the "differences" above, divided by the surplus fall per station, gives the number of stations within which the permitted maximum velocity will be attained, as in the first part of the table above. The number of stations × rate of grade per cent gives the second part of the table.

road-bed in good condition, can be operated by all trains with almost as great safety at 25 to 30 miles per hour as at any lower speed, if the speed does not require to be suddenly checked. In ascending such a grade the same conditions obtain as in descending, except (1) that the locomotive ascends the grade using steam, whereas it descends without steam; and (2) that it starts or may start with the high velocity which gradually decreases instead of with the low velocity which gradually increases. We are not now considering the effect of limiting gradients, which is an entirely different matter, but assuming that the locomotive has sufficient power to ascend all grades at necessary speeds, as of course in all cases it must. The cost of decreasing the length and increasing the number of trains to effect this end, which constitutes the chief objection to gradients, is not now under consideration at all.

449. SUMMARIZING THE PRECEDING DISCUSSION of the nature of rise and fall, we have found that it may be divided into the following classes, having a very different effect on operating expenses:

Class A. Rise and fall on minor gradients and for small undulations, not sufficient to make it necessary to vary the power of the engine, but merely causing a momentary, gradual, and unobjectionable fluctuation of speed.

Class B. Rise and fall similar to class A, in its effect in speed, provided steam be shut off in descending, but not requiring the use of brakes in descending, nor seriously taxing the power of the engine on the ascent. Tables 121–2 give the limits of this class.

Class C. Rise and fall requiring the use of brakes in descending, in addition to shutting off steam, in order to avoid excessive velocities, and consequently, in almost all cases, more or less use of sand in ascending.

450. Rise and fall is most conveniently estimated by the number of VERTICAL FEET of it, since the cost of it (which includes no limiting effect on trains) depends primarily on the length of grades and not at all on their rate, except as the rate may change the rise and fall from one to the other of the above classes. A foot of "rise and fall" is ordinarily considered as one foot of ascent with its corresponding foot of descent, so that in passing over a hill 100 feet high there are 100 feet of rise and fall, and not 100 feet ascending + 100 feet descending = 200 feet.

451. The amount of rise and fall of each kind on the profile should be determined thus:

A. All rise and fall arising from hollows in grade-lines not exceeding the limits specified in connection with Table 121 (par. 435 *et seq.*), if the grades are connected by easy vertical curves and are not too near stations, or very bad curvature, will belong to the least objectionable class, A. If the hollows are sharp and abrupt, however, even if quite small, the rise and fall will be more objectionable than the worst class here considered.

B. All rise and fall on grades too long to come under Class A, but on rates of grade so easy that the train can never obtain

a dangerously high velocity when running without brakes with steam shut off, will belong to Class B. So also will rise and fall on any grade, however steep, which is not long enough for the train to obtain a dangerously high velocity, as fixed in Table 122 and par. 447 *et seq.* So also, strictly speaking, will the upper part of any grade, however steep and however long, on which no dangerously high velocity can result according to Table 122; but it would be an objectionable refinement, tending to an under-estimate of the cost of bad details of location, to so consider.

C. Class C, therefore, should be considered to include the entire length of all grades so long and steep as to require the use of brakes in descending.

The ruling grade of the line may belong to either Class B or Class C. In either case it will involve the occasional use of sand and more or less slipping of wheels, and perhaps breaking in two of trains in ascending, and thus make an addition to the cost of either class which would not apply to the same grades if they were not ruling grades, and hence did not so severely tax the power of the engine.

The limit of these classes will vary in every case, but there is a tolerably sharp line of demarcation between the cost of each, which may be estimated as follows:

THE COST OF RISE AND FALL.

452. FUEL.—Except as wasted by brakes, there is no loss of power (energy), and except as wasted by brakes and radiation combined, there is no loss of either fuel or power, from any amount of rise and fall of Class A, if we neglect the slight difference in frictional resistances resulting from a (so to speak) regularly irregular speed instead of from a uniform speed averaging the same in miles per hour. This necessarily follows from elementary dynamic laws. Even if there be a difference in the level of the two termini, what power is lost in going in one direction is regained in returning.

When, in the case of rise and fall on easy gradients requiring no brakes (Class B), we run a part of a distance of one or two miles (the ascent) under steam and another part of it (the descent) with steam shut off, assisted by gravity only,—or in other words, assisted by the energy

stored in the train during the run over the up grade by the act of lifting it against gravity,—the total time that the locomotive is exposed to exterior radiation is the same, and probably also the loss of heat. The loss from interior radiation in the cylinders, a very important loss, explained in Chapter XI., is affected as follows:

It is increased by the (probable) lower piston speed in ascending the up grade.

It is decreased by the (probable) later point of cut-off, and hence less oscillation of temperature in the cylinder; the disadvantage of this latter very nearly balancing, as experiment shows, the theoretical gain from an earlier point of cut-off. This is to say, from both of these causes combined, the steam used for equal work in the locomotive engine is about the same at all points of cut-off less than half stroke; which leads to the conclusion that the steam (not fuel) used to run an engine two miles will be about the same whether the work is uniform for the whole run or is all done during the first mile in taking the engine up an easy grade, down which it runs by gravity for the second mile. The loss by external radiation during the last mile will be a net loss. The fuel used will probably be much more increased, not only by possible blowing-off of steam from the safety-valve, but by blowing out more unconsumed coal from and wasting more heat through the smoke-stack, owing to the stronger draft. In Chapter XI. it is shown that in proportion as the work of the engine is increased, economy of fuel consumption is decreased.

From all these causes combined a locomotive running without brakes or steam down grades too steep to continue the steam-power unchanged, but not steep enough or long enough to require the use of brakes, will burn probably one fourth to one fifth more, and certainly not over one third more fuel in ascending one mile on the grade equal to the grade of repose (assumed at 26 feet per mile, or 0.5 per cent), and then descending one mile without steam, than in running two miles on a level. Allowing one third more, 80 vertical feet of rise and fall on such grades will waste fuel equal to the average consumption per mile.

453. *When brakes are required*, owing to the grade being either too steep or too long to permit of operating it without them, the power used in ascending is entirely lost, except that portion of it which is just sufficient to keep the train in motion on the grade of repose. That is to say: The rise and fall at *FCD*, Fig. 85, consists of two parts, the upper part, *B*, belonging to Class B, and the lower part only, *C*, belonging to Class C, which is very much more costly, objectionable, and dangerous. In laying out a line this fact must be borne in mind; the lower portion, *C*, estimated

at its true value and avoided if possible; the upper portion, *B*, less carefully avoided. The limit between classes B and C may be taken in round figures as the height of the point *b*, Fig. 85, above or below the grade of repose descending from *A*, although, strictly speaking, the grade of repose should be drawn in starting from the point on the grade where the limits of Table 122 and par. 447 are passed, so that dangerously high speed before reaching the foot of the grade is certain. But when this point is once passed great care in handling the train on a grade where brakes are known to be essential cannot fairly be assumed, so that it is fairer and more reasonable to assume that all the fall, *C*, Fig. 85, will be of the objectionable class.

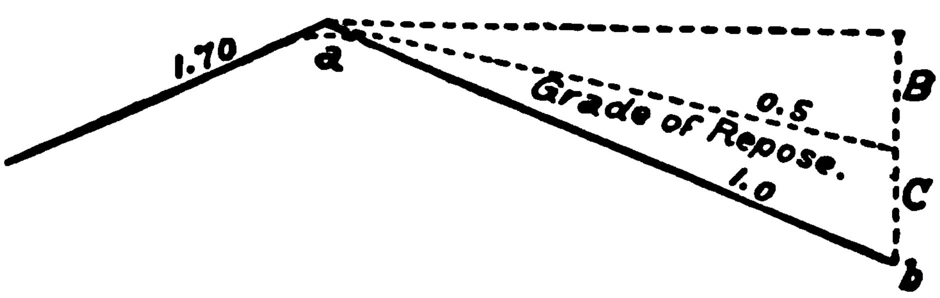


FIG. 85.

When an engine is descending a grade without steam, the wastage of fuel by radiation and slow combustion is at first (say for 10 or 15 minutes) very considerable—about one fourth of the usual consumption per mile. The loss of fuel on this most objectionable class of rise and fall may be taken as equal to the average consumption in running a mile for every 26 feet of rise and fall.

454. REPAIRS OF CARS AND LOCOMOTIVES.—The use of brakes is excessively destructive to wheels. Table 114, page 318, will make it clear that something like one third of the total cost of wheels arises from this cause, and other data that as much as forty or fifty per cent arises from them. Brakes, however, are used even more for stopping and starting than on grades—sometimes very much more; and the whole cost of wheels is only some 30 per cent of freight-car repairs and very much less of passenger cars. The records of wheels drawn on the Pennsylvania Railroad indicate (*a*) that about 30 per cent of passenger-car wheels are drawn for being "worn flat from sliding," and that their life is from this cause abbreviated from one third to one half. About one sixth of the wheels are drawn for being "worn flat or hollow on tread," which class of wear is distinctly ascribed in the Pennsylvania classification to "wear from rail."

If we should consider only such facts as these, we might reach the conclusion that the wear due to grades must be a very important element in the cost of freight-car repairs; but by referring to Table 86, page 203, and remembering that grades are only one of many causes for wear and tear of cars, we shall see reasons for concluding that, while it is exceed-

ingly difficult, in fact impossible, to reach an exact estimate in such a mattter as this, yet that it is not probable, if all grades were levelled down flat so as not to require in any case the use of brakes, except for stops, wheel renewals would not be reduced more than one sixth nor car repairs as a whole more than one tenth. The only item of car repairs other than the wheels affected to an important extent is the cost of draw-gear and links and pins, and the loss in this respect, as we have seen (par. 419), arises more from lack of proper vertical curves at breaks of grade than from the grades themselves.

TABLE 123.

VARIATIONS IN THE QUALITY OF WATER SUPPLY, CHICAGO, BURLINGTON & QUINCY RAILROAD.

LOCALITY.	GRAINS PER GALLON.		Lbs. Incrusting Matter in Tank of 2750 Gallons.	Comparative Incrusting Matter. Lake Michigan = 1.00.
	Incrusting Solids.	Alkalies and Non-crusting.		
Chicago Division:				
Best	10.666	1.365	4.19	1.5
Worst	28.851	10.788	11.33	3.9
Average	16.405	2.853	6.44	2.2
St. Louis Division:				
Best	4.898	1.458	1.92	0.7
Worst	20.178	2.449	7.93	2.8
Average	11.490	1.678	4.51	1.6
Lake Michigan	7.305	0.626	2.87	1.0
Hudson River	7.177	1.136	2.82	1.0
Croton River, N. Y	5.362	1.511	2.11	0.7
Loch Katrine, Scotland	0.911	1.333	0.36	0.1

Incrusting solids include silica, oxide of iron and alumina, carbonates of lime and magnesia, and sulphates of lime and magnesia.

The standard tank of the road carries 2750 gallons.

The non-incrusting matter may be partly deposited as mud and partly mechanically combined with the scale. According to this table, an engine consuming three full tanks of water per day would in a week's work with the average water in the Chicago Division accumulate at least 116 lbs. of incrustation. With the best water on the St. Louis Division (taken from the Mississippi at Rock Island) the result of a similar week's work would be only 34½ lbs. of incrustation. The difference shows the importance of good water.

The water of Loch Katrine, Scotland, from which Glasgow derives its supply, is about the purest and softest known.

455. The cost of locomotive tires will be affected in much the same way and to the same extent as the cost of car wheels. The life of the boiler is likewise unfavorably affected by an intermittent instead of regular demand for power, although this effect is slight in comparison with the injury suffered from the cooling off of boilers at the end of the trip, from the effect of bad water and many other causes not connected with the grades between stations. Table 123 gives an idea of how important is the effect of bad water on locomotive repairs.

456. It is, moreover, true of both engine and car repairs that, as noted in par. 164, when we search for evidence of the effect of much rise and fall, or curvature, or (as usually happens) both together, by comparing the cost of engine and car service per mile run on roads or divisions having much and having little curvature and rise and fall, we fail to find it. As respects grade, this results in part, no doubt, from lower speed and more careful handling on them; but as this costs the company nothing except a slight delay, we may fairly regard it as an offset, to some extent. In the first edition of this treatise the writer estimated the effect of rise and fall at 5 per cent, on the total cost of repairs of engines and cars per mile, for each 25 feet per mile (0.5 per cent, nearly) which would amount in 2 per cent grades to something over 20 per cent per mile of ascent and descent. Taking an average of the mountain divisions of the Pennsylvania Railroad, this would require that a difference of at least 15 per cent should be visible, and on the Baltimore & Ohio at least 20 per cent, whereas in fact no such difference appears in either case. This fact, together with a careful estimate by items, which cannot be given more fully than above, leads the writer to believe that his original estimate was too high and it is reduced in the estimate below (Table 124) to 4 per cent, which is the utmost that the statistical evidence seems to justify.

On Class A of rise and fall there cannot be considered to be any measurable increase in the cost of rolling-stock maintenance if proper vertical curves are used. On Class B (requiring shutting off steam for descending, but not the use of sand or brakes) there is very little—certainly not over one fourth of what exists on the worst class, C.

457. WEAR OF RAILS.—The effect of grades on the wear of rails is exaggerated in popular belief for want of a proper distinction between the effect of a heavy ruling grade, which increases the number of trains and the proportion of engine tonnage, and the effect of rise and fall simply, on which the number of trains and proportion of engine tonnage is the same as on adjacent sections of level track. Thus, in an able and

elaborate report on the wear of rails on the Pennsylvania Railroad, already quoted, an increase of some 75 per cent in the wear of rails on grades over which almost three times as many engines pass as on adjacent sections of level track was ascribed to the effect of grades as such, whereas it is in reality merely an expression of the fact that an engine wears the rails several times as much as the same weight of cars (par. 115). In so far as this is the cause of extra wear of rails it is an effect arising from the LIMITING effect of gradients, and not at all an inherent property of gradients as such.

When we eliminate this extraneous question we are driven to the conclusion that the wear of rails due to gradients as such is almost *nil*, except as their rate may be such to require the use of brakes and sand. The use of sand is exceedingly destructive to rails. The writer found that at specially exposed localities (near stations for the most part), where the use of both brakes and sand was usual, the wear as measured by loss of weight was increased some 75 per cent; but loss of weight alone is an unfair criterion, since the wear at joints is a very important factor in the life of rails, and often requires their removal before they are fully worn out. Such extreme use of either brakes or sand, moreover, is not common on any grade as at the points covered by the writer's tests.

458. In the first edition of this treatise, a considerable body of statistics being presented and discussed to which it appears unnecessary to again give space, the writer estimated that the wear of iron rails was increased not over 5 per cent per 25 vertical feet of rising grade and the same on the corresponding descent, or 10 per cent for each 25 feet of rise and fall, making, on a 2 per cent grade (106 feet per mile) a difference of 20 per cent in the aggregate of this item on both the ascent and corresponding descent. He sees no reason to believe that this estimate is materially in error in either direction (unless in excess) as measuring the effect of gradients pure and simple, *without modification in the number of engines used for a given number of cars*, and this latter occurs only on the worst class of rise and fall, C. For that class, a proper estimate for iron rails might be expected to still hold good for steel, since the proportion of the grade wear to the level wear has not been greatly affected by the introduction of steel on such steep grades, where speed is slow.

On Class A there is certainly no direct evidence that the wear of rails is affected at all, with steel rails. With iron rails, which failed mostly from lamination and which speedily wore to an irregular surface on top, on which any considerable increase of speed caused greatly increased wear and tear, the case was different.

Class B of rise and fall likewise has little effect to increase rail wear, but as it is apt to cause a somewhat high velocity in the hollows, it undoubtedly has some ill effect; possibly about one half as much as Class C.

459. MAINTENANCE OF ROAD-BED AND TRACK.—In the former edition of this treatise the cost of these items was estimated as increased in about the same ratio as the rail wear, viz., 5 per cent for each 25 feet per mile (0.5 per cent nearly) of rise and as much for the corresponding fall. A liberal estimate in such a matter is proper, and we may continue the former estimate for Class C, although it is probably somewhat too high for average conditions.

On Class A and Class B the disadvantages and advantages of the grade may be fairly considered to balance each other as respects maintenance of road-bed and track. A great compensating advantage from the grade, besides the lower speed, is the more perfect drainage, giving a firmer road-bed and prolonging the life of ties and ballast as well as preserving the surface. Level cuts are always very objectionable, as has been rediscovered many times since one of the early English engineers laid out one several miles long, which caused immense difficulty (and still causes it), several costly tunnel culverts having to be driven to drain it. Grades of any moment are usually situated in comparatively rugged and difficult regions, and the increased expense arising from that cause is very apt to be erroneously ascribed to the effect of the gradients themselves. Creeping of rails is an annoying effect due in part to gradients, but has been largely done away with in recent years by improved forms of joints.

460. TRAIN WAGES.—It is quite conceivable that one or more additional brakemen may be required on a line of much rise and fall, yet it would ordinarily be quite improper to include this as one of the expenses arising from it, for this reason: Whether or not such additional force will be required is usually determined by the general character of the line beyond hope of change by the engineer. In comparing two radically different lines, it might be an element worthy of consideration, but the slight modifications which are ordinarily alone possible can rarely be sufficient to in themselves make any difference in this respect.

461. STATION, TERMINAL, AND GENERAL EXPENSES, as well as train wages and a large proportion of the other running expenses, cannot be considered as affected to any appreciable extent by any changes in rise and fall not of the most radical and extensive nature.

462. From all that has preceded we may deduce that no leading item of railway expenditure is largely affected by rise and

fall in itself, and very many of them not at all affected. In Table 124 appears a detailed summary of the aggregate effect to increase expenses of each of the three classes of rise and fall, A, B, and C:

A. Not requiring shutting off steam nor change in the natural velocity, nor use of brakes or sand. (See foot-note to Table 124.)

B. Requiring shutting off steam at the head of the grade, but not use of brakes or sand.

C. Requiring use of both brakes and sand.

463. The summary of the cost per year of a foot of rise and fall at the foot of Table 124 shows its cost to be—

	Class C.	Class B.	Class A.
Cost on minor gradients..............	$2 67	$0 84	$0 28
Cost on ruling gradients.............	3 50	1 67	——
Addition to cost of same amount of rise and fall if on ruling gradient.......	0 83	0 83	——

These sums, divided by the rate of interest on capital, whatever it may be, will give the JUSTIFIABLE EXPENDITURE PER DAILY TRAIN to avoid one foot of rise and fall. Thus, if capital cost 6 per cent, the justifiable expenditure per daily train to avoid 100 feet of rise and fall (i.e., 100 feet up, with the corresponding 100 feet down) will be for each class,—multiplying the above sums by 100 and dividing by 0.06,—

	Class C.	Class B.	Class A.
If on minor gradients................	$4,450	$1,400	$467
If on a ruling gradient...............	5,833	2,783	——
To reduce the ruling to a minor gradient (leaving the ruling gradient elsewhere unchanged).................	1,383	1,383	——

It would be impossible, however, that there should be so much as 100 feet of rise and fall of Class A at any one point, since if there were so much, or even half or one quarter so much, it could not belong to Class A. The value given for reduction of a ruling to a minor gradient refers, of course, merely to the DIRECT saving of wear and tear by having the grade easier, and

TABLE 124.

ESTIMATED COST PER TRAIN-MILE AND PER DAILY TRAIN OF 26.4 FEET OF THE VARIOUS CLASSES OF RISE AND FALL.

(Cost of train-mile assumed at $1.00.)

ITEM.	Total Cost of Item.	Percentage of same increasing with 26.4 feet of rise and fall belonging to— Class C.	Class B.	Cost per train-mile of 26.4 feet of rise and fall belonging to— Class C.	Class B.
		p. c.	p. c.	p. c.	p. c.
Fuel	7.6	100	33⅓	7.6	2.53
Water, oil, and waste	1.2	50	20	0.6	0.24
Repairs of engines	5.6	4.0	1.0	0.22	0.06
Switching-engine service	5.2	Unaffected.		....	....
Train wages and supplies	15.4	"		....	....
Repairs of cars	10.0	4.0	1.0	0.4	0.10
Car-mileage	2.0	Unaffected.		....	....
Renewals of rails	2.0	10.0	5.0	0.2	0.10
Adjusting track	6.0	5.0	0.0	0.3	0.00
Renewing ties	3.0	5.0	0.0	0.15	0.00
Earthwork, ballast, etc	4.0	5.0	0.0	0.2	0.00
Yards and structures	8.0	Unaffected.		....	....
Station and general	30.0	"		....	....
Total	100.0	9.7	3.0	9.67	3.03
Per Foot of Rise and Fall				.366	.115
Per Foot of Rise and Fall per Daily Train (round trip)				$2.67	$0.84

IF THE RISE AND FALL BE ON THE MAXIMUM GRADE, whether on Class B or Class C, the wear and tear of rolling-stock and track will be so increased as to add at least 3.0 cents per train-mile to the cost of 26.4 feet of rise and fall, giving us the following comparison :

	Class C.	Class B.
Cost per daily train per foot of rise and fall on MINOR GRADIENTS, as above,	$2.67	$0.84
Addition to cost of the same grade if a RULING GRADIENT due to the extra wear and tear on ruling gradients,	0.83	0.83
Giving as the cost per daily train per foot of rise and fall on RULING GRADIENTS,	$3.50	$1.67

A Foot of Rise and Fall means a foot of ascent with its corresponding descent (par. 450).

CLASS A OF RISE AND FALL is not included in this table, because, as will be seen from the preceding discussion of the details of expenses, no expense can be directly traced to it in any single item. In considering this apparently doubtful conclusion the strict limitations laid down for the class in par. 435 *et seq.* are to be remembered. Moreover, although the effect on expenses of rise and fall of this class is so small as to defy separate estimation by items, yet as it causes some variation in the velocity of the train there must be considered to be some disadvantage arising from such rise and fall for this cause alone, and it will lead to no serious error to assume its cost at *one fourth to one third the cost of Class B.*

not at all to the much greater value which results from reducing all ruling grades throughout the line, so that the length of trains can be increased.

464. The above values are to be further multiplied by the estimated number of trains per day (round trip). Thus, if there are expected to be 10 trains per day each way, the value of substituting a level for a hill 100 feet high becomes $14,000 to $44,500 for minor gradients, and $27,830 to $58,330 for ruling gradients—which are very considerable sums if we remember that they are quite apart from all limiting effect of the gradients. The value of changing the rise and fall from Class C to Class B is nearly $30,000, and of reducing a ruling gradient to a minor gradient without changing the class, nearly $14,000.

465. In the first edition of this treatise the cost of rise and fall on all grades of over 40 feet per mile was found to be—

On	12½	feet per mile (about	0.25) grades	$1 04
"	25	" " " ("	0.5) "	1 56
"	35	" " " ("	0.7) "	1 87
"	40 to 50	" " " ("	0.8 to 1.0) "	2 08
"	80	" " " ("	1.5) "	2 29
"	125	" " " ("	2.5) "	2 40

The writer has been forced to the conclusion that these estimates were too small to be on the safe side, and, despite the fact that the steel rail and other mechanical betterments have materially reduced the disadvantages of rise and fall, has increased its estimated cost as above.

466. It will be clear from all that has preceded in this chapter that the disadvantages of rise and fall are measured more truly by the number of BREAKS OF GRADE than by the actual amount of it in vertical feet, except on the worst class of all, C, on which both brakes and sand have to be constantly used. Even on the heaviest grades this is in a measure true. Thus, the long 1 per cent grade in Fig. 86, belonging to Class C, will be considerably more objectionable to operate than a corresponding easy grade belonging to Class A or B of rise and fall, as the 0.5 continuous grade in Fig. 86; but the breaking up of the 1 per cent grade at frequent intervals by stretches of lighter grade, so that the

descent is made half on one grade and half on the other, so far from decreasing the aggregate cost of the grade over the straight

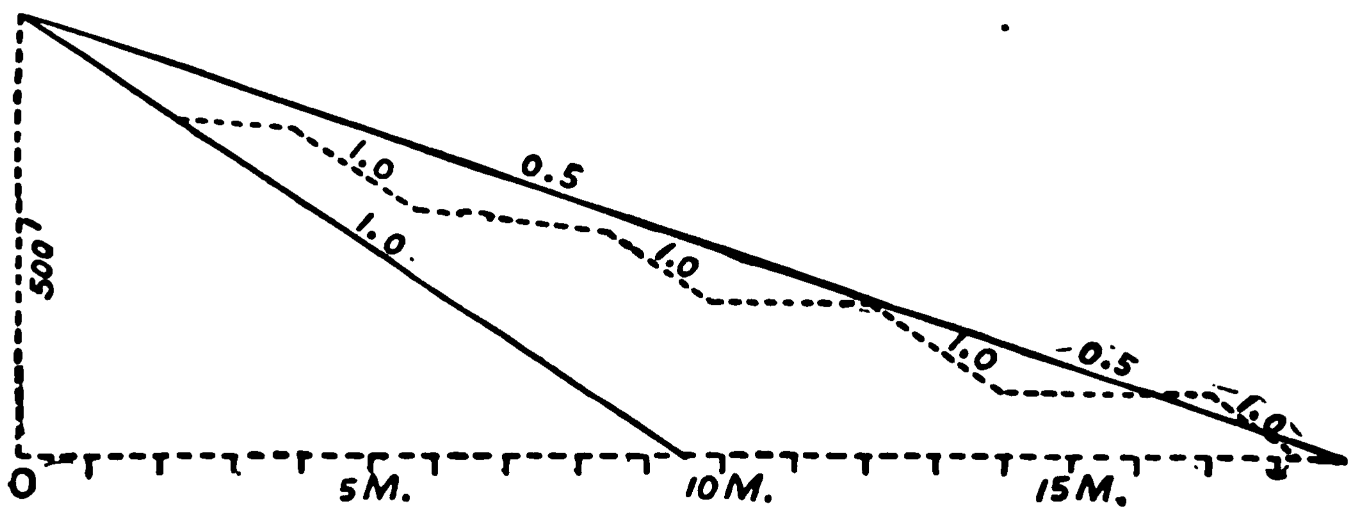


FIG. 86.

1 per cent, will in fact make it considerably more expensive to operate.

467. Again, 1000 feet of rise and fall concentrated on a single grade is not nearly so expensive in wear and tear as when the same amount of it is scattered around in a dozen or more shorter and widely scattered grades of the same rate and class (par. 462). If its class is changed by such breaking up the case is different. Thus. the least objectionable class, A, of rise and fall can only exist when there is very little at one point.

468. We have seen (par. 414 *et seq.*) that long and easy vertical curves, properly used, very largely obviate the disadvantages of every class of rise and fall, however much broken up into short sections; in fact, properly used, they forbid the breaking it up into over-short sections.

It is so extremely important that vertical curves should be sufficiently long and should be properly put in, that we may anticipate here, from the field-book which follows this volume, some notes as to the proper manner of putting in such curves:

469. We have seen (par. 426 *et seq.*) that the length of vertical curves should be determined, not arbitrarily, regardless of the angle between gradients, but by the amount of change of grade per station which is admissible; the safest rule being as already given—that the difference in the rate of grade under the head and rear of the train shall not exceed the grade of repose of the last car.

A rate of change per station (100 feet) of .025 will most completely

25

fulfil this condition with all kinds of trains, including those with a great deal of slack in the couplings, like coal trains; but .05 per station will obviate all the more serious effects, especially if the speed be high or the train short, or both. After the introduction of improved freight couplers .05 per station will be ample.

Both of these rates give a longer curve than is usual; but more change

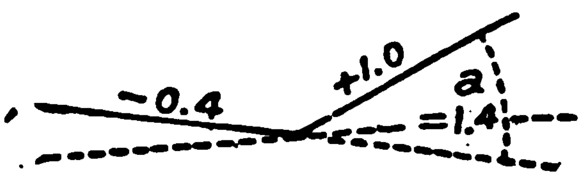


FIG. 87.

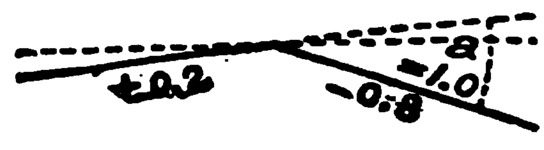


FIG. 88.

per station than that last specified should never be used in sags (Fig. 87), unless for high speed and very short trains. On summit curves (Fig. 88) shorter curves are admissible; but these also should not be shorter than 0.1 per station—if for no other reason, because it is needless to make them so.

470. The angle between grade-lines, a, Figs. 87, 88, is considered to be the sum or difference in the rate per cent of the grades, or their deflection from each other. In Fig. 87, $a = 1.4$; in Fig. 88, $a = 1.0$, etc.

If we let $r =$ the change of rate per station which is considered admissible, $= 0.025$ to 0.10 according to circumstances, then the aggregate length of any curve is at once given by the equation

$$l = \frac{a}{r}.$$

If the angle between grade-lines be 1.0 per cent, this gives a vertical curve 10, 20, or 40 stations long, according as the assumed value of r is 0.1, 0.05, or 0.025.

The condition that the change in rate of grade shall be uniform per

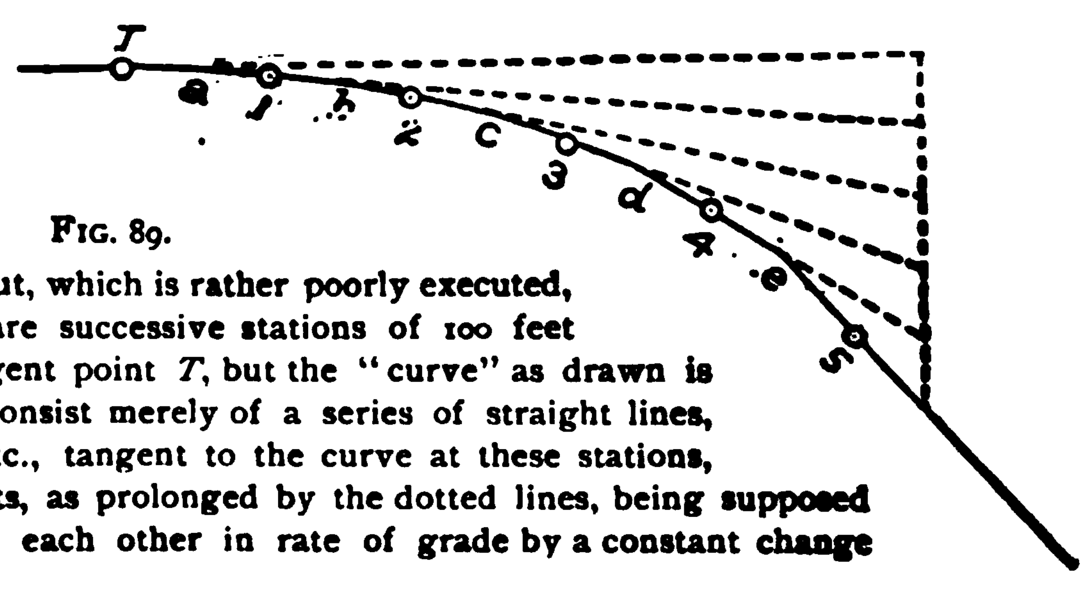


FIG. 89.

(In this cut, which is rather poorly executed, 1, 2, 3, 4, 5 are successive stations of 100 feet from the tangent point T, but the "curve" as drawn is supposed to consist merely of a series of straight lines, ab, bc, cd, etc., tangent to the curve at these stations, these tangents, as prolonged by the dotted lines, being supposed to differ from each other in rate of grade by a constant change of rate, r.)

station or other unit results in the generation of a curve such as that outlined in Fig. 89, which is, mathematically, a parabola.

471. It is to be remembered that all geometrical diagrams connected with railway location are greatly exaggerated or distorted, so that the succession of chords outlined in Fig. 89 are in fact practically coincident with the curve. Fig. 90 gives to correct scale the intersection of a 4 per cent (211 feet per mile) grade with a level, which is perhaps twice as large an intersection angle as actually occurs on any located line in the United States, even on the engineer's profile, and four or five times as much as is usual; topographical reasons generally requiring one or more intermediate grades in cases of such abrupt change.

Fig. 90 will also make it clear that in the two sketches of vertical

FIG. 90.

curves shown in Figs. 91 and 92 the tangents, the chord M, and the curves themselves are sensibly of the same absolute length, independent of the fact that, all distances being measured horizontally, they are necessarily equal as measured in the field.

472. From the law of the parabola it results that in any vertical curve, Fig. 91 or 92, the curve bisects the middle ordinate IM in c, and from elementary geometrical relations we have for the distance $Ic = c$, by which the curve departs vertically from the intersection of tangents:

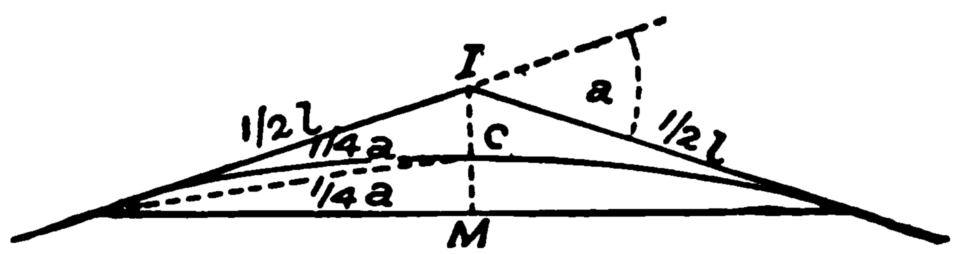


FIG. 91.

$$c = \frac{l}{2} \times \frac{a}{4} = \frac{la}{8};$$

or, as $l = \dfrac{a}{r}$ (par. 470),

$$c = \frac{a^2}{8r}.$$

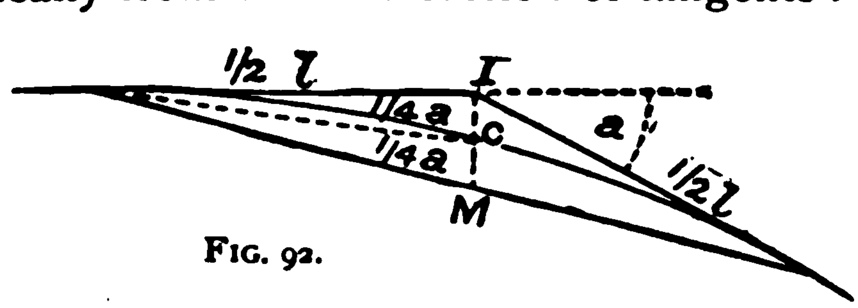


FIG. 92.

473. From this formula we can compute the following Table 125, giving the first detail which it is desirable to know in laying out a vertical curve, viz.: How much vertical change it will produce in the position of the grade-line, which is greatest at the middle of the curve and thence rapidly diminishes in each direction, being only one fourth as much at the "quarter-points" of the curve or at the middle of each tangent.

474. Having determined from Table 125, or otherwise, what rate of per station will be necessary or feasible: TO LAY OUT A VERTICAL CURVE, HAVING GIVEN THE RATE OF THE TWO GRADIENTS AND THEIR ANGLE

TA[illegible]

VERTICAL CHANGE IN THE POSITION [illegible] 72.0)
OF GRADIENTS RESULTING [illegible]
AND WITH VARIOUS GRADE-A[illegible]

(Comp[illegible]

GRADE-ANGLE a. FIGS. 91, 92.	VERT[illegible] GRAD[illegible] 0.2
	Feet.
0.1	.00[illegible]
0.2	.025
0.3	.0[illegible]
0.4	.1[illegible]
0.5	.1[illegible]
0.6	.[illegible]
0.7	
0.8	
0.9	
1.0	
1.1	
1.2	
1.3	
1.4	
1.5	
1.6	
1.7	
1.8	
1.9	
2.0	

....	1.0
....	0.05
....	20 stations.
.....	90 / 110
......	108.0 / 102.0

[illegible]	STATIONS.
[illegible]	90
[illegible]	91
[illegible]	92
[illegible]	93
[illegible]	94
[illegible]	95
[illegible]	96
[illegible]	97
[illegible]	98
[illegible]	99
[illegible]	100
[illegible]	101
[illegible]	102
[illegible]	103
[illegible]	104
[illegible].625	105
[illegible]1.6	106
[illegible]1.625	107
[illegible]1.7	108
[illegible]1.825	109
102.0	110

The vertical [illegible] curve, or at the [illegible]

The whole le[illegible] [illegible] most convenient when the curve [illegible] be assumed to do so by comput-[illegible]. In other cases the following

OF INTERSE[illegible]
THE INTERSEC[illegible]

1. The total [illegible] Fig. 96, offsets to it from its stations), one ha[illegible] vary as the square of the distance station of th[illegible]: HAVING GIVEN O AND N, Fig. 96, grade at that poi[illegible] CURVE, o, o', o'' at distances n, n', n''

2. Having given the station and elevation on either grade, and the rate (which let $= R$) of the grade in which it lies, write successively $R - \frac{1}{2}r$, $R - 1\frac{1}{2}r$, $R - 2\frac{1}{2}r$, etc., adding or substracting r from each (as the case may require) until n quantities have been written down, paying strict attention to the algebraic signs, as below specified.

The nth quantity thus determined will differ from the rate R' of the other tangent by $\frac{1}{2}r$, and the addition of the several quantities thus determined to the elevation of the first tangent-point will give the elevation of each station of the curve, to and including the other tangent-point, where the elevation will check upon that independently fixed by the tangent grade-line for the second tangent, if the work has been correctly done.

When the angle between the grade-lines is upward, or on a summit, the successive additions of r are $-$, or subtractions; when the angle of the grades is downward, the additions are positive.

EXAMPLES.—Curves to connect the gradients shown in Figs. 93, 94, 95, each with the intersections of gradients at station 100 and elevation 100.

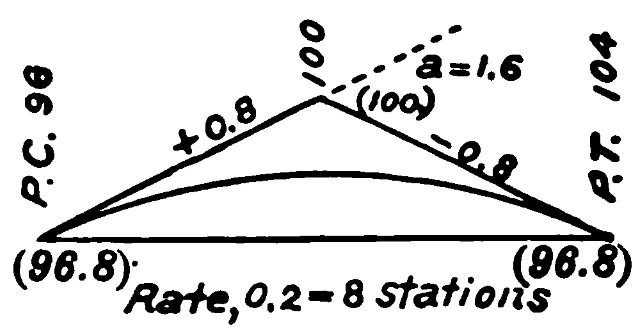


FIG. 93.

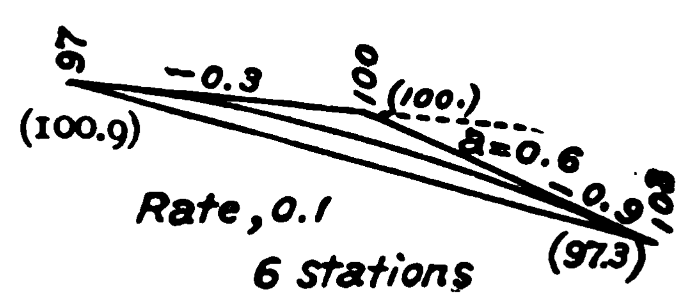


FIG. 94.

	FIG. 93.	FIG. 94.
Angle between grade-lines........ .	1.6	0.6
Rate of change of grade per station.	0.2	0.1
Total length of curve..............	8 sta.	6 stations.
Station of tangent-points....	96 104	97 103
Elevations of grade at do. (computed).	96.8 96.8	100.9 97.3

	ADDITIONS.	ELEVATIONS.	STATIONS.	ADDITIONS.	ELEVATIONS.	STATIONS.
P. C............	.	96.8	96		100 90	97
$R - \frac{1}{2}r$.........	0.7	97.5	97	— 0.35	100.55	98
$R - 1\frac{1}{2}r$........	0.5	98.0	98	— 0.45	100.10	99
$R - 2\frac{1}{2}r$..	0.3	98.3	99	— 0.55	99.55	100
$R - 3\frac{1}{2}r$........	0.1	98.4	100	— 0.65	98.90	101
Etc..........	— 0.1	98.3	101	— 0.75	98.15	102
	— 0.3	98.0	102	— 0.85	97.30	103
	— 0.5	97.5	103			
P. T...........	— 0.7	96.8	104			

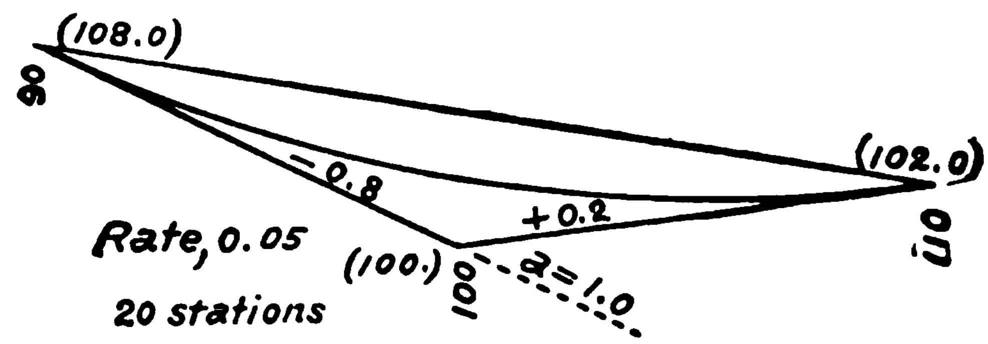


FIG. 95.

Angle between grade-lines..........................	1.0
Rate of change of grade per station..................	0.05
Total length of curve	20 stations.
Station of tangent-points.......................	{ 90 110
Elevation of grade at tangent-points.................	{ 108.0 102.0

ADDITIONS.		ELEVATIONS.	STATIONS.
P. C.		108.0	90
$R - \frac{1}{2}r$	− .775	107.225	91
$R - 1\frac{1}{2}r$	− .725	106.5	92
$R - 2\frac{1}{2}r$	− .675	105.825	93
$R - 3\frac{1}{2}r$	− .625	105.2	94
etc.,	− .575	104.625	95
	− .525	104.1	96
	− .475	103.625	97
	− .425	103.2	98
	− .375	102.825	99
	− .325	102.5	100
	− .275	102.225	101
	− .225	102.0	102
	− .175	101.825	103
	− .125	101.7	104
	− .075	101.625	105
	− .025	101.6	106
	+ .025	101.625	107
	+ .075	101.7	108
	+ .125	101.825	109
P. T.	+ .175	102.0	110

This method is practically much the most convenient when the curve begins and ends at a full station, or can be assumed to do so by computing grades for half stations or otherwise. In other cases the following may be used :

475. By the property of the parabola, Fig. 96, offsets to it from its tangents parallel to the " diameter," O, vary as the square of the distance from the tangent-point. Therefore: HAVING GIVEN O AND N, Fig. 96, TO DETERMINE OFFSETS TO THE CURVE, o, o', o'' at distances n, n', n'' from the *P. C.*

Letting N = the length of one tangent we have, for any offset o whatever at a distance n from the $P.\ C.$,

$$\frac{O}{N^2} = \frac{o}{n^2}, \text{ whence } o = O\frac{n^2}{N^2}$$

Thus, if we divide the tangent N into five parts the first offset, o, will be $O \times \frac{1^2}{5^2}$, or $\frac{O}{25}$, and the succeeding ones will be 4, 9, 16 times the first.

By this formula we may compute the elevation of any two points 100

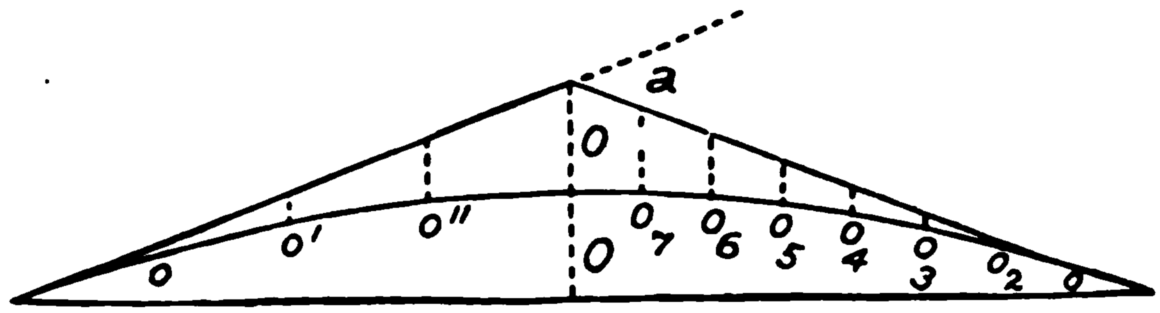


FIG. 96.

feet apart on any vertical curve (presumably at full stations) and determine the rate of grade between them; whence, knowing the change per station in rate of grade, all remaining stations are determined by successive additions as above. To avoid cumulative error, the computation should be carried out to more decimals than it is expected to use.

The entire curve may likewise be computed by determining the offsets o, o', o'', which ordinarily involves little labor.

The introduction of close couplers is now (1890) rapidly reducing the need for very long vertical curves.

PART III.

LIMITING GRADIENTS AND CURVATURE.

"The crime which bankrupts men and states is, job-work;—declining from your main design to serve a turn here and there."

—R. W. EMERSON, *Essay on "Wealth."*

PART III.

LIMITING GRADIENTS AND CURVATURE.

CHAPTER X.

THE RELATIVE IMPORTANCE OF GRADIENTS.

476. To summarize the conclusions we have reached in the preceding four chapters as to why the minor details of alignment are properly so called, both separately and collectively: Let us assume that we have a line over which an estimated traffic of 10 trains per day each way will pass,—a very fair traffic,—and that we have two alternate lines for it, one of which (A) is 200 miles long, while the other (B) is 210. Let line A have the favorable alignment of the Illinois Central, which (Table 102) has only 8° of curvature per mile, and line B the very crooked alignment of the Lehigh Valley, which has 100° per mile, giving 1600° in all on line A against 21,000° in all on line B. Let the rise and fall on A average only 10 feet per mile, or 2000 feet in all, instead of 20 feet per mile on B, or 4200 feet in all; always assuming, however, that the ruling gradients and length of trains are the same on each. Then the entire value of these very marked and very improbably great differences in minor details will be as follows:

per train-mile, but simply in the number of trains required to handle the traffic. The distinction between these diverse sources of expense was so fully drawn in Chap. IX. that it need not be repeated, but it should be always borne in mind. For the present we assume the gradients to be the limiting cause, as is nearly always the case, although it may be curvature or—conceivably—any other cause, like the strength of couplings.

480. To be prepared to deal intelligently with questions of gradients we must begin from the foundation and consider, in some detail, what we may call the physiology as distinguished from the anatomy of the locomotive engine, especially as respects the running gear. The general question of limiting gradients will then divide itself naturally into the following different heads:

First. Ruling gradients proper, and their effects on train-loads and operating expenses (Chaps. XIV., XV.).

Secondly. The use of concentrated or "bunched" grades on high rates, operated by assistant engines or "pushers," with lower grades elsewhere, as against uniform gradients (Chap. XVI.).

Thirdly. The proper balance of grades from excess of traffic in one direction (Chap. XVII.).

Fourthly. Limiting curvature, which may intervene in advance of gradients to limit the length of trains (Chaps. XVIII., XIX.).

Fifthly. The choice of gradients and devices for reducing them (Chap. XX.).

All of these problems come up, potentially at least, in the location of every line. Before attempting to solve them we will lay the necessary basis therefor in the three following chapters on the Locomotive Engine, Rolling-Stock, and Train Resistance.

CHAPTER XI.

THE LOCOMOTIVE ENGINE.*

481. THE locomotive engine is, so far as the skill and foresight of the designers can make it, and practical considerations permit, a delicately-balanced machine, having these three forces in equilibrium for the particular service required of it:

1. THE STEAM-PRODUCING OR BOILER POWER: the boiler, fire-box, and attached parts.

2. THE MECHANICAL OR TRANSMITTING POWER: developed through the cylinder and attached parts, and transmitted to the driving-wheels.

3. THE TRACTIVE POWER OR ADHESION for exerting or transmitting the energy produced; developed through the frictional resistance to sliding of the drivers on the rail.

482. THE AMOUNT AVAILABLE of each of these forces is:

BOILER POWER.—*Limited* by the quantity of steam which can be produced in a boiler of admissible weight and size.

CYLINDER POWER.—*Indefinitely great.* The cylinder is a mere transmitting machine for the transformation of one form of energy into another, and can be adapted (within wide limits) to the transmission of any amount of power (ft.-lbs.) in any desired ratio of speed (ft.) to force (lbs.) by mere variation of proportions.

TRACTIVE POWER.—*Limited* by the total weight of the machine and the proportion thereof which can be placed on the coupled driving-wheels.

483. Thus it is seen that the limit to the work which can be done by any well-designed engine lies either in the boiler power or in the adhesion, and never in the cylinder, which latter always has, or should have

* The writer had gone more fully into the theory of the locomotive than was absolutely essential, and he finally concluded, more fully than was wise, in the belief that a broader general knowledge of the locomotive by civil engineers would in many ways conduce to good practice; but in order to keep the volume within reasonable size he finally concluded to abbreviate this chapter very materially from his original draft. Much of the data thus prepared was thought to be entirely new, and still more of it has not been systematically presented in treatises on the locomotive, but it must be given in another form, if at all.

(in any engine of ordinary type), power in excess of either what can be transmitted by the adhesion or developed through the boiler, or both. That the cylinder power should be in excess of one or the other of the other two, under all ordinary circumstances, as it is, is plain. The ultimate power of the engine is fixed by the weakest one of these three forces. Two of them can only be increased by radical modifications of the machine, while the other can be made as great as desired (within wide limits) by trifling modifications of detail, affecting cost and weight but very slightly. Therefore, it is plain, it would be inexcusable neglect not to make the link in the chain whose strength we can control strong enough to certainly utilize the full strength of the other two, which we cannot control, without a radical change in the machine; so that the ultimate power of the machine as a whole should never, at any time or under any circumstances, fall by mere negligence in design below the limits fixed by natural causes.

484. That the comparative conditions stated in regard to the possibility of increasing these three forces do in fact prevail, is evident from the data as to comparative weights of the various parts of a locomotive engine given in Table 126: TO INCREASE THE BOILER POWER OF THESE ENGINES 10 PER CENT (assuming it to be possible at all without exceeding the admissible load per wheel or the limits of physical possibility) means an increase of nearly 10 per cent in the weight of the boiler and at least 5 per cent in the weight of the rest of the engine. As this would increase the available adhesion it would naturally lead to increasing the

TABLE 126.

COMPARATIVE WEIGHT IN LBS. OF THE VARIOUS PARTS OF A LOCOMOTIVE ENGINE.

	Total Weight in Service. Lbs.	Boiler and Attached Parts varying therewith.		Cylinders, Valve-gear, and Connecting Rods.	Running Gear.	Frame.	Cab, Smoke-box, Lagging, and Miscel. Trimmings.
		Water.	Metal.				
Light American......	60,807	6,000	15,989	10,032	16,663	5,121	7,002
	100.0	9.9	26.3	16.5	27.4	8.4	11.5
Consolidation, Penn.. Class I............	91,640	9,543	24,262	15,397	26,119	7,500	8,819
Per cent	100.0	10.4	26.5	16.8	28.5	8.2	9.6

The light American engine is that given in detail in Table 133; the Consolidation is given in detail in Tables 129 and 132. The singular constancy of ratio in the weights of these widely different locomotives is notable.

cylinders correspondingly, but even without doing so we have an increase of about 7 per cent in the weight of the machine.

485. To increase the cylinder power 10 per cent we have only to decrease the size of the drivers, effecting an actual decrease in the weight of the machine. For, since the cylinder pressure (which let $= C$), whatever it be, acts with a leverage of half the stroke ($= s$) against a leverage of half the diameter of the driver ($= R$), we have, for the tractive force exerted by the cylinders,

$$T = \frac{sC}{R} \text{ and } C = \frac{TR}{s}.$$

To increase T by any amount without changing either the stroke (s) or the diameter of the cylinder (C) we have only to decrease R. This, however, is at the expense of increasing the piston speed, because, as the driver is made smaller, it must turn so much oftener per mile.

486. To increase the cylinder power 10 per cent without increasing the piston speed, however, nothing more is required than the addition of from 2 to 8 per cent to the weight of the cylinders and attached parts alone, the remainder of the machine remaining unaffected except in a few trifling details. Whether the increase be 2 or 8 per cent depends chiefly on how it is effected—whether it be by merely lengthening the cylinder or by increasing its diameter; but in either case the total addition to the weight and cost of the machine is trifling. Assuming 8 per cent added to the weight of the cylinders, it amounts (see Table 126) to but a little over one per cent of the whole weight of the engine.

487. Cylinder power may also be increased after the machine is completed by the simple, but ordinarily not permissible or wise, expedient of increasing the boiler pressure. It has also been not unfrequently decreased in the same way, so as to be smaller than either the boiler power or traction, with unfortunate results upon the efficiency of the engine.

488. To increase the tractive power 10 per cent, or by any other amount, we must either increase the load per drivers or the number of drivers, or both. The possibility of increasing the load per wheel is strictly limited by that which the permanent way and structure will sustain. The load per wheel is in practice, and for certain reasons may properly be in theory, greatest with those engines (fast passenger engines) which have and require the least amount of total tractive power. To increase the number of drivers we must take a new type of engine, and here, too, the range is strictly limited. A few special engines excepted, the largest number of drivers now in practical use on a large scale is eight (Consolidation and Mastodon types), and the least, four (American type), with a few extra fast but very heavy engines having only a single

[illegible] power 25 per cent we [illegible] which means in-[illegible] per cent. We [illegible] weight of engine.

[illegible] . . . 7 to 8 per cent.
[illegible] 1 to 1½ "
[illegible] . 50 to 60 "

[illegible] is a mere matter of ad-[illegible], and hence should always [illegible] the other two.

499. For the very reason that the amount of cylinder power is a mere detail of mechanical design, having no natural limit in either direction, it furnishes a [illegible] measure of relative capacity and power for comparing one engine with another. In other words, cylinders of the same size can be said with far more [illegible] to give engines of always equal power than a similar identity in any other one detail of the locomotive. A "17 / 24" engine, which is now looked on as the standard or unit type, may be either a fast passenger or a slow freight engine, but it will always be, roughly speaking, of about the same weight and cost, and will ordinarily exert and be capable of exerting about the same amount of power (foot pounds) in the same time.

500. This is therefore a very common and often all-sufficient description of an engine, when it is desired to give a general idea in a few words of its character, but this should not lead to the mistaken conclusion (as it sometimes does) that the cylinder is an important element of design in a locomotive in the sense of being a governing element by which its power in service is limited. On the contrary, the logical order of design (but not necessarily for that reason the order that a practised designer will follow) is—

First, to fix the total admissible or desired weight of the machine.

Secondly, (in a freight engine) the proportion of this weight which can be utilized for adhesion, or (in a passenger engine) the largest boiler power which can be gotten without exceeding that weight.

Thirdly, to adapt the boiler power and adhesion to each other; and,

Fourthly, to fix the size of the cylinders to correspond, making sure to have them large enough.

There is a serious disadvantage in having cylinders unnecessarily large for the work to be done, due to external and internal radiation, which limits somewhat the wide discretion specified, but not so greatly as to affect the substance of what has been said.

501. The boiler power of a locomotive, like that of any other source of energy or dynamic force, is ultimately measurable in *foot-pounds per*

hour, or other unit of time. So far as boiler power is concerned, therefore, a locomotive is capable of hauling any load whatever if the speed be made low enough, or of attaining any speed whatever at the expense of the load hauled.

HORSE-POWERS or other equivalent units are merely certain multiples of foot-pounds. Whatever the name of the unit for the measurement of energy, it is always made up of the three elements of lifting a certain *weight* through a certain *distance* in a certain *time* against the natural force of gravity, gravity being the only constant and ever-present force with which we are familiar, and hence a natural unit for comparison.

492. The tractive power is measurable only in POUNDS, being a mere static or dead force, serving for the transmission of energy, like a belt or a shaft, but not affecting its amount. The tractive power is—with important limitations to be considered—an approximately constant quantity at all speeds and under all circumstances.

493. Therefore, remembering (1) that the cylinder power is not an element in fixing the working power of an engine, and (2) that speed includes the two elements of time and space, which, with the third ele-

FIG. 97.—INDICATING THE MANNER OF ADAPTING THE SAME BOILER POWER TO PASSENGER OR FREIGHT SERVICE.

ment, weight or force, make up the three which are necessary for the exact description of the amount of any kind of power, we may express

graphically the variations which can be made in the manner of utilizing or distributing the power of an engine as follows (Fig. 97):

494. On a pair of co-ordinate axes intersecting at O, Fig. 97, let distances on the vertical axis OA represent pounds of tractive power, and distances on the horizontal axis OC represent the compound unit *speed*, including the two primary units, distance and time.

Then the capacity of any given boiler, which is measurable only by a product of the three units, *lbs.* × *ft.* × *time*, may be represented on such a diagram by a rectangle of a given fixed AREA ($OABC$, $OA'B'C'$, $OA''B''C''$) which may be proportioned in any ratio of height to length desired, provided the total area included within it be not exceeded. The number of such possible rectangles, as will be apparent from the figure, is infinite.

As a matter of mere mathematical curiosity, of no immediate practical moment, it may be noted that if an HYPERBOLA be drawn passing through the point B, with the axes OA, OC, as asymptotes, any point B' on it will be the apex of a rectangle of always equal area.

495. Each one of these rectangles will represent a possible locomotive, each different from the other, which may be designed to fit the same boiler,—with this sole limitation: The tractive power in pounds of ordinary forms of locomotives is a limited quantity, which cannot be indefinitely increased; and consequently at a certain point on the diagram A' we reach a vertical limit, beyond which it is not possible, by any ordinary device, to increase the tractive power. It follows directly from this fact that we have a certain minimum of speed OC', below which it is not possible to decrease the speed and still utilize the full power of the boiler by increasing the load hauled. As might naturally be expected, this limitation is at times very inconvenient, when it is desired to obtain the maximum hauling capacity regardless of speed, as in engines for yard service or for working on heavy grades. It is, in fact, practically, the most serious theoretical defect of the locomotive. Various exceptional devices are employed to evade it in part, the simplest and most common of which is to carry the water supply, and sometimes the fuel also, upon the driving wheel-base. A still more radical remedy is mentioned in par. 511, and yet another device is the so-called TRACTION-INCREASER, throwing a part of the weight of the tender on the drivers for the time being by cylinders attached to the piston, or by various combinations of levers. Finally, the device of a rack between the rails, or of a central rail which the driving-wheels grip by spring power or other pressure, enables the gravity of the engine to be wholly dispensed with for furnishing the trac-

tive force, by substituting for it frictional adhesion, and thus removes all limit whatever to the load that a given boiler can move, provided the speed be made slow enough.

496. When this is done, all limits to the diagram in Fig. 97 are likewise removed: so that it then becomes literally true that, so far as boiler-power is concerned, there is no limit whatever to either the speed of a locomotive or to the load it can haul, provided one decreases as the other increases; but since the load to be hauled can in no case be decreased below the weight of the engine itself, a limit of possible speed is soon reached as well as of tractive force, and the limit of expediency in each direction is much narrower than that of possibility.

A very interesting and instructive study of the differences of designs in locomotives and of the causes therefor, which the writer feels compelled to omit, may be made by constructing diagrams similar to Fig. 97 for various actual locomotives; laying off the load on drivers on the vertical axis; taking the boiler power as proportional to the heating surface, and adding various details of grate-area, etc.

497. It will be sufficiently clear from what has preceded, that in the practical working of engines a deficiency in any one of the three co-ordinate forces which when combined make the complete machine will be shown in the following ways:

1. *If adhesion or tractive power be the smallest* of the three, the engine will slip her drivers.

2. *If boiler power be the smallest*, the boiler pressure as indicated by the steam-gauge will fall, and the engine will from this fall of pressure be unable to turn the wheels.

3. *If cylinder or engine power be the smallest*, the engine will be stalled while utilizing to the utmost a full pressure of steam and while yet unable to slip its drivers.

498. The last is either an evidence that the engine is out of the service for which it was designed,—as for instance a fast passenger engine hauling freight trains,—or it is an evidence of bad design. It is one of the most discreditable faults an engine can have, for the reason that it is an entirely unnecessary sacrifice of a portion of its capacity for work, and it is, naturally, a fault of rare occurrence. It has occurred in instances on a considerable scale, however, as an effect of cutting down the permitted boiler pressure to 120 lbs. after copying the general proportions of engines designed to carry 130 or 140 lbs. The effect of such action on the pounds of tension which can be exerted is the same, and

as injurious, as if the boiler power itself had been reduced, which latter, however, does not at all follow from the reduction of pressure (par. 552).

499. The indication of deficient hauling power first above specified, slipping of drivers, is that which should first occur in all well-designed freight engines; for, since hauling-power and not speed is the desideratum in such engines, the boiler-power, however small (within limits), can be made to exert an indefinitely great force in pounds at the expense of speed, by proper design of the engine; which can hence be so designed that the boiler shall be able to exert continuously a force always in excess of the tractive power when at its maximum (as when using sand) by a little at least, in order that the full measure of the latter may in all cases be utilized.

500. This theoretical principle is limited in part by this fact: Convenient operation, requires that it should not be too easy to slip the drivers under ordinary conditions but should require nearly a full head of steam to do so, or the difficulty of throttling the pressure just right (par. 527) will lead to too frequent slipping. Hence it is desirable that the cylinder power should be only a little in excess of the adhesion, and from this it may result that the ultimate maximum of adhesion, when using sand on a dry rail with boiler pressure perhaps a little low, cannot be advantageously realized. There are also certain disadvantages in an over-large cylinder, from greater loss by radiation, condensation. etc., as well as some advantages. See also foot of page 408.

501. But it is probable that all these disadvantages have been over-estimated, or the whole question inadequately considered, in designing many of the engines now running, a considerable minority of which cannot utilize the full ultimate adhesion, and are in consequence compelled to haul smaller loads than they otherwise might; although most freight engines can slip their drivers in ordinary working, when starting or running very slowly, and do so liberally. No well-designed engine will slip its drivers when running at speed, unless the rails are in bad order, as the average cylinder pressure is then much lower than in starting (par. 594). Over-frequent slipping of drivers is an evidence of want of skill or care in the engineman. He can with ease slip the drivers with the lightest train or with no train at all, and in fact must use care not to, unless the cylinders are too small for the engine, because only an infinite force can set in motion the lightest body instantly.

502. The second indication of deficient hauling capacity above specified, deficiency of boiler power, is the only one, in theory, by which a passenger engine should ever fail; since a fraction only of its weight, if on the drivers, will give a hauling power in *pounds* far in excess of the available *foot-pounds* of boiler power at a high speed in feet per minute. Neither do passenger engines often fail, in fact, for any other cause, between stations, on moderate grades. The necessity of starting heavy trains

quickly. however, and of maintaining a high rate of speed even on long, heavy grades, makes the demand for adhesion on passenger engines very unequal, and at times very great, so that it is often in practice the actual limiting cause which it is desirable to increase. It is not essential to do this permanently. Any device which increases the load on the drivers temporarily, especially for stopping or starting, answers every purpose, and a better purpose in fact than a permanent increase. Such attachments are now in use on extra-fast engines and to a limited extent on others, and it is probable that their use, or that of some equivalent, might be greatly extended, for both passenger and freight engines, without any disadvantage at all comparable to the gain.

503. But however well an engine may have been designed for the average contingencies of ordinary service, when the engine is once in service there are limitations to or variations in the efficiency of each of its three primary forces which have an important effect upon the load it can haul, and which we need to consider.

In the following Tables 127 to 137 are given a variety of data as to the dimensions, weight, cost, and life of locomotives which we shall have occasion to use or refer to, which are here grouped together for convenience of reference.

TABLE 127.

COMPARATIVE DIMENSIONS OF ENGINES OF THE AMERICAN TYPE.

	17 × 24 CYLINDERS.				18 × 24 CYLINDERS.			
	Mason. 1873.	No. Pac. 1884.	Brooks. 1884.	C., B. & Q. 1884.	C., B. & Q. 1884.	Mason. 1884.	West Shore. A.	West Shore. B.
Weight on drivers	40,000	54,350	48,000	53,600	54,500	68,000	64,000	62,500
Weight on truck	22,000	19,450	26,000	27,600	28,300	32,000	32,000	32,000
Weight, total (lbs.)	62,000	83,800	74,000*	81,200	82,800	100,000	96,000	94,500
	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
Grate surface	16.38	16.	16.45	17.6	17.7	18.9	34.	17.
Heat'g surf'ce: Fire-box	105	117	103.	98.	102.	145.	128.	128.
Heat'g surf'ce: Tubes	906	I 1218	E 990.	I 968.	I 958.	E 1230.	E 1084.	E 1084.
Heat'g surf'ce: Total	1011	1335	1093.	1066.	1060.	1375.	1212.	1212
Barrel of boiler	46"	51"	48"	49⅛"	49⅛"	54"	55"	
Diameter of drivers	66"	62"	67"	69"	69" p. / 65" ft.	68"	68"	
TENDER:								
Weight, lbs.: Empty	....	27,900	....	24,183	24,183	....	34,000	
Weight, lbs.: Load	....	29,438	....	37,467	37,467	....	30,000	
Weight, lbs.: Total	....	57,338	....	61,650	61,650	....	64,000	
Capacity: Water (galls.)	2,250	2,800	2,640	2,750	2,750	3,600	3,000	
Capacity: Coal (lbs.)	....	6,105	....	14,550	14,550	....	10,000	
WHEEL-BASE:								
Driving	8' 0"	8' 6"	8' 0"	8' 6"	8' 6"	9' 0"	8' 6"	
Total engine	22' 0"	23' 3¼"	22' 7"	22' 6¼"	22' 6¼"	23' 4"	22' 9⅜"	
Tender	....	....	....	14' 11"	14' 11"	....	15' 8"	
Engine and tender	....	45' 1¼"	42' 6"	44' 9"	44' 9"	....	47' 4⅞"	

* Weight, empty, 66,000 lbs., leaving 8000 lbs. for contents of boiler and fire-box, and two men.

TABLE 128.

COMPARATIVE DIMENSIONS OF MOGUL AND TEN-WHEEL ENGINES.

	MOGULS.				TEN-WHEEL.	
	Baldwin 18 × 24. 1873.	Brooks 18 × 24. 1883.	B. & O. 19 × 24. 1883.	N. S. Wales. (Baldwin) 18 × 26 1884.	Baldwin 18 × 26. 1873.	Brooks 19 × 24. 1883.
Weight on drivers	66,000	72,500	87,400	79,000	58,000	73,100
Weight on truck	11,000	13,500	....	17,000	20,000	21,400
Weight, total (lbs)	77,000	86,000*	....	96,000	78,000	94,500†
	sq. ft.	sq. ft.		sq. ft.	sq. ft.	sq. ft.
Grate surface	16.	17.	....	17	14.4	22.6
Heating surface, Fire-box	103.	114.	....	123.	94.	128.4
Heating surface, Tubes	948.	1141.	....	I 1066.	1014.	1422.4
Heating surface, Total	1051.	1255.	....	1189.	1108.	1550.8
Barrel of boiler	50″	52″	....	55″	50″	52″
Diameter of drivers	52″	55¾″	60″	60⅛″	54″	55¾″
TENDER:						
Weight, lbs., Empty	....	....	....	31,500	....	....
Weight, lbs., Load	....	....	....	41,200	....	....
Weight, lbs., Total	....	....	....	72,700	....	....
Capacity, Water (galls.)	2,200	2,880	....	3,600	2,200	2,880
Capacity, Coal (lbs)	....	....	....	10,000	....	....
WHEEL-BASE:						
Driving	15′	15′ 6″	....	15′ 0″	13′	14′ 0″
Total engine	22′ 8″	23′ 0″	....	23′ 2″	23′ 6″	25′ 3″
Tender	....	....	....	14′ 6″	....	....
Engine and tender	....	....	....	46′ 2⅛″	....	45′ 7″

* Weight, empty, 78,000 lbs., leaving 8000 lbs. for contents of boiler and fire-box.
† Weight, empty, 84,300 lbs., leaving 10,200 lbs. for contents of boiler and fire-box.

The Baltimore & Ohio Mogul carries 140 lbs. of boiler pressure, affording a maximum average cylinder pressure of some 119 lbs. (85 per cent of boiler pressure). At this rate the cylinder tractive force is 17,184 lbs., or about $\frac{1}{5}$ weight on drivers. In most American engines it is about $\frac{1}{4}$, and in some as low as 0.30.

The tendency in recent years has been strongly toward increase of weight and boiler power with the same-sized cylinders, as Tables 127 to 130 and Table 142 bring out very clearly. Three concurrent causes have brought this about: (1) The material increase in steam pressure, which makes a smaller cylinder do much more work; (2) the higher average speed of trains, which necessitates larger boiler power to maintain it; and (3) the fact that the more perfect track has justified and the lower rates required loading engines up to the last limit of their tractive power, and it was necessary to have as much as possible under all conditions of rail and weather.

TABLE 129.

COMPARATIVE DIMENSIONS OF THE ORIGINAL AND PRESENT STANDARD CONSOLIDATION LOCOMOTIVE OF THE PENNSYLVANIA RAILROAD, AND OF THE WEST SHORE STANDARD CONSOLIDATION.

	Class I. 1876.	Class R. 1886.	Increase.	West Shore. 1883.
Size of cylinders	20 × 24″	20 × 24″	*None.*	20 × 24″
Weight on drivers	79,400 lbs.	100,600 lbs.	27 p. c.	88,000 lbs.
" " truck	12,240 lbs.	14,025 "	14.6 "	16,000 "
Total wheel-base	21′ 6″	21′ 9″	3″	21′ 7″
Driving-wheel base	13′ 8″	13′ 10″	2″	14′ 0″
Diameter of drivers	50″	50″	*None.*	50″
Working pressure	125 lbs.	140 lbs.	12 p. c.	140 lbs. (?)
BOILER:				
Inside diam. smallest boiler-ring	53⅜″	59″	10.5 p. c.	55″
Tubes { No. and size (outside)	138, 2⅛″	183, 2⅛″	32.6 "	169, 2¼″
Tubes { Length	12′ 11″	13′ 1 11/16″	....	13′ 4¾″
Fire-box { Length	96″	107″	11.5 p. c.	95⅜″
Fire-box { Width	34⅛″	42″	21.8 "	34⅛″
Fire-box { Depth	42 to 61″	57 to 59⅛″	....	....
Grate surface	23 sq. ft.	31.2 sq. ft.	35.6 p. c.	23 sq. ft.
Heating surface { Fire-box	92 " "	167 " "	81.5 "	120 " "
Heating surface { Tubes	E 1,166 " "	E 1,564 " "	34.2 "	E 1,340 " "
Heating surface { Total	1,258 " "	1,731 " "	37.5 "	1,460 " "
Smallest inside diameter chimney	20″	18″	− 2″	......
Height top of rails to top of chimney	14′ 11″	15′ 0″	1″	13′ 6½″
TENDER:				
Weight { Empty	22,770 lbs.	23,800 lbs.	4.5 p. c.	29,000 lbs.
Weight { Load	33,000 "	33,000 "	*None.*	35,000 "
Weight { Total	55,770 "	56,800 "	1.8 p. c.	64,000 "
Capacity { Water	3,000 galls.	3,000 galls.	*None.*	3,000 galls.
Capacity { Coal	8,000 lbs.	8,000 lbs.	"	10,000 lbs.
Wheel-base	15′ 4″	15′ 4″	"	15′ 8″
ENGINE AND TENDER:				
Total wheel-base	47′ 7″	48′ 9″	1′ 2″	47′ 7″
Length over all	56′ 9⅜″	58′ 5⅛″	2′ 3⅞″	56′ 8½″

The following are some further details in respect to the changes in the latest Pennsylvania Consolidation from the earlier design :

CYLINDERS.—*Unchanged:* diameter of piston-rod, size of ports, travel and outside lap of valves, size of slide-blocks. Piston-head, 1 in. thicker; cylinders, 2 in. farther apart (7 ft. 2 in.) ; inside lap, none (in place of 1/32 in.) ; lead, 1/16 for ⅛ in.; steam-pipe, 19.6 for 18 sq. in.; each blast-nozzle, 13.8 for 11.2 sq. in.

JOURNAL.—All increased materially. Driving-axles, from 6½ × 7½ to 7 × 8½ ; truck-axles, from 4½ × 7 9/16 to 5 × 8 9/16 ; crank-pin, from 4½ and 5 to 5 and 6 in. Coupling-rod and journals *unchanged*, 3½ in.

BOILER.—*Unchanged:* material (steel ; wrought-iron tubes), distance between centres of tubes (3½ in.); thickness fire-box plates (⅜ in. outside ; 5/16 in. inside), tube-plates (½ in.). Barrel-plates, ½ and 7/16 in. for ⅜ in.; butt-joints, welted inside, for lap. Water grate for shaking grate.

TENDER.—*Unchanged:* tank, 19 ft. × 43 in. high.

The West Shore Consolidation was designed by the late Howard Fry, one of the most eminent of American mechanical engineers, and was designed to include all the latest improvements up to its date.

TABLE 130.

COMPARATIVE DIMENSIONS OF ENGINES MORE POWERFUL THAN THE CONSOLIDATION TYPE.

	MASTODON TYPE. (8 drivers; 4 truck-wheels.)		"EL GUBERNADOR" (Cent. Pac.). (10 drivers; 4 truck-wh'ls)	DECAPOD (Baldwin). (10 drivers; 2 truck-wh'ls)
	Central Pacific.	Lehigh Valley.		
Size of cylinders	19 × 30"	20 × 26"	21 × 36"	22 × 26"
Weight on drivers	106,050 lbs.	82,432 lbs.	121,600 lbs.	128,000 lbs.
" " truck	16,950 "	19,264 "	32,400 "	16,000 "
Total wheel-base	24' 11⅛"	23' 2"	28' 11"	24' 4"
Driving wheel-base	15' 9"	13' 0⅜"	19' 7"	17' 0"
Diameter of drivers	54"	48"	57"	45"
Working pressure	135 lbs.	125 lbs.	140 lbs. (?)	....
BOILER:				
Inside diam. smallest boiler-ring	54"	51"	56⅞"	64"
Tubes: No. and size (outside)	166, 2¼"	199, 2"	178, 2¼"	268, 2"
Tubes: Length	12'	10' 11⅛"	12' 0"	12' 9⅛"
Fire-box: Length	13' 4⅛"	11' 6"	....	10' 1"
Fire-box: Width	34"	34"	....	39⅛"
Fire-box: Depth	39⅛ to 58⅛"	43⅛ to 52⅛"	....	....
Grate surface	25.74 sq. ft.	32 sq. ft.	....	....
Heating surface: Fire-box	182 " "	179 " "	....	....
Heating surface: Tubes	I 1,076 " "	I 995 " "	....	....
Heating surface: Total	1,258 " "	1,174 " "	....	....
Smallest inside diameter chimney	20"	17"	....	....
Height top of rails to top of chimney	15' 6⅛"	14' 7"	....	....
TENDER:				
Weight: Empty	26,000 lbs.	23,400 lbs.	50,650 lbs.	....
Weight: Load	37,000 "	30,418 "	35,000 "	....
Weight: Total	63,000 "	53,818 "	85,650 "	80,000 lbs.
Capacity: Water	3,000 galls.	2,575 galls.	3,000 galls.	3,500 galls.
Capacity: Coal	12,000 lbs.	8,960 lbs.	10,000 lbs.	....
Wheel-base	15' 0¾"	....	....	....
ENGINE AND TENDER:				
Total wheel-base	53' 1¾"	46' 9"	....	....
Length over all	64' 0"	55' 4"	65' 5"	....

These four engines are as yet the most powerful in the world. A Fairlie engine weighing about 85 gross tons and having two six-wheel driving-trucks, each with 17 × 22 cylinders, with a Bissell (pony) truck at each end, is running on the Iquique Railway, in Peru. Other heavy locomotives are given in Table 137.

The Central Pacific Mastodon (the original of the type) has hauled 20 loaded cars, weighing 422 tons, up a long grade of 116 ft. per mile. By Table 170 it should haul 421 tons. At 8 miles per hour it is reported to have shown an average pressure of 124 lbs. per square inch in the cylinders. "El Gubernador," cutting off at five-sixths stroke, at a speed of 6¾ miles per hour, showed an average of 115 lbs. with 130 lbs. boiler pressure, or 88 per cent, which is much nearer to boiler pressure than is often possible, and develops the enormous tractive power of 32,039 lbs., or just 39 lbs. more than one fourth the weight on drivers. As this is about the very utmost the cylinders can do, it indicates that the cylinders, large as they are, might with advantage be larger, or the boiler pressure higher.

TABLE 131.

COMPARISON OF COST OF THE ENGINES (WITH TENDER) GIVEN IN THE FOLLOWING TABLE 134, **per Ton (2240 lbs.) of Engine only in Service,** INCLUDING ALSO CERTAIN ENGINES OF THE GREAT WESTERN RAILWAY OF ENGLAND.

For percentages of cost see Tables 66, 67.

NATIONALITY.	ROAD.	Class of Engine.	Weight in Service, Engine only. Tons.	Cylinders. in.	COST PER LONG TON, *Actual.*				Correction, per cent on Materials.	COST PER TON, *Corrected.*	
					Materials.	Labor.	Shop and General.	Total.		Materials.	Total.
American....	Penna. R. R..	Cons'n "I"...	40.9	20×24	$147.00	$97.02	$42.15	$286.17	....	$147.00	$286.17
"	" "	H'y Pass. "C"	33.8	17×24	164.77	76.98	43.55	285.30	....	164.77	285.30
English......	Great S. & W.	Light Pass...	27.2	16×20	215.05	82.39	41.20	338.64	21.7%	168.25	291.84
"	" "	Heavy Pass..	30.3	17×22	214.05	85.42	42.71	342.18	21.3%	168.25	296.38
"	" "	Heavy Fr'ght	30.0	17×24	235.10	79.03	39.51	353.64	22.8%	181.40	299.94
"	Great West'n.	Light Pass...	27.5	16×24	150.35	72.17	36.67	259.19	15%	127.80	236.64
"	" "	Heavy Pass..	31.0	17×24	168.88	70.86	43.65	283.39	15%	143.51	258.02
"	" "	Heavy Fr'ght	30.5	17×24	152.29	67.71	44.62	264.62	15%	129.46	241.79
French.......	Paris and Orl.	Heavy Fr'ght	29.5	(17×24)	230.94	90.73	53.85	375.52	27.6%	167.04	311.62

MARKET PRICE OF THE BALDWIN LOCOMOTIVE WORKS AT ABOUT THE SAME DATE (1876) FOR LOCOMOTIVES OF VARIOUS WEIGHTS.

For cost of other engines see Tables 62, 63, page 150.

WEIGHT OF Engine.	APPROXIMATE COST			Per Cent of Increase in Total Cost.
	Per Long Ton.	Per Pound.	Total.	
20 tons	$350	15.6 cts	$7,000	....
30 "	275	12.2 "	8,250	17.9
40 "	230	10.3 "	9,200	31.4

In 1870–74 these prices were about 20 per cent higher.

This table is deduced from the records given for the same engines in Table 134, which latter this table should properly follow, had convenience in making up the tables into pages permitted.

TABLE 132.

WEIGHTS AND COST OF MATERIALS FOR AMERICAN LOCOMOTIVES (PENNSYLVANIA RAILROAD STANDARDS).

The cost of tender for Class "C," if not also for "I," is undoubtedly too large, but it is impossible to determine wherein the error lies. The total cost of engine and tender is presumably correct.

TABLE 133.

WEIGHTS IN DETAIL OF AN OLD ILLINOIS CENTRAL PASSENGER ENGINE, 16 × 22 CYLINDERS.

[Abstracted from a record taken by Mr. M. N. Forney.]

	Weights—Lbs.				
	Brass.	Wrought Iron.	Cast Iron.	Wood, etc.	Total.
Boiler sheets, rivets and stay-bolts	......	6,299	......	......	6,299
Braces, crown-bars, etc	......	1,635	......	......	1,635
Tubes and copper thimbles	......	3,034	......	......	3,034
Ring for dry-pipe, furn'e-door, etc.	40	90	17	......	147
Dome	75	24	845	......	944
Dry-pipes	38	103	93	12	246
Throttle-valve, etc	13	110	193	......	316
Steam and exhaust pipes	10	11	377	......	398
Petticoat-pipe	......	52	......	......	52
Blower	16	38	......	......	54
Smoke-box door	9	45	336	......	390
Smokestack	......	452	200	......	652
Grate	......	175	1,333	......	1,508
Ash-pan	......	314	......	......	314
Total Boiler	201	12,382	3,394	12	15,989
Frames	......	3,552	......	......	3,552
Boiler-braces	......	628	......	......	628
Bed-casting	......	29	912	......	941
Total Frames	......	4,209	912	......	5,121
Cylinders	110	65	2,795	136	3,106
Steam-chest	36	80	805	......	921
Valves	18	82	132	......	232
Pistons	......	127	262	......	389
Cross-head guides	12	681	240	......	933
Connecting-rods	117	609	42	......	768
Crank-pins	......	166	......	......	166
Driving-wheel boxes	112	6	430	......	548
Valve-gear	......	740	984	......	1,724
Reverse-lever	2	221	19	.....	242
Pumps	436	253	163	......	852
Pump-check valves	39	12	100	......	151
Total Machinery	882	3,042	5,972	136	10,032
Driving-wheel centres	......	......	5,324	640	5,964
" " tires	......	3,360	......	......	3,360
" " axles	......	1,033	107	......	1,140
Truck-wheels	......	......	1,884	......	1,884
" axles	......	604	......	......	604
" frames, boxes, etc	72	1,181	1,058	......	2,311
" check-chains	......	131	......	......	131
Driver springs, steel	......	416	......	......	416
" attachments	......	506	.. ...	10	516
Truck springs	......	337	......	......	337
Total Running Gear	72	7,568	8,373	650	16,663

TABLE 133.—*Continued.*

	Weights—Lbs.				
	Brass.	Wrought Iron.	Cast Iron.	Wood, etc.	Total.
Safety-valve	53	26	7	......	86
Steam gauges and cocks	73	26	......	......	99
Cylinder cocks and fittings	10	57	12	......	79
Injector	66	21	50	......	137
Sand-box	45	144	283	......	472
Bell and clapper	80	9	......	......	89
" stand	68	10	52	......	130
Hand-rail	63	44	......	......	107
Running-board	60	101	......	334	495
Wheel-covers	139	337	120	......	596
Cab and foot-board	4	565	446	1,083	2,098
Pilot	......	757	77	320	1,154
Head-light bracket	15	11	68	49	143
Lagging and sundries	114	329	......	874	1,317
Total Fittings	790	2,437	1,115	2,660	7,002
Tender tank	......	3,515	......	......	3,515
Fittings for ditto	19	37	103	3	162
Frame	.....	1,124	722	2,327	4,173
Truck-wheels	......	......	3,952	......	3,952
Axles and collars	......	1,272	......	..	1,272
Axle-boxes	......	......	536	......	536
Bearings and fittings for ditto	64	29	32	12	137
Springs	......	880	......	......	880
Trucks and other parts	......	1,330	1,596	670	3,596
Brakes	......	143	46	106	295
Total Tender	83	8,330	6,987	3,118	18,518

SUMMARY.

	Brass.	Wrought Iron.	Cast Iron.	Wood, etc.	Total.
Boiler	201	12,382	3,394	12	15,989
Frame	......	4,209	912	......	5,121
Machinery	882	3,042	5,972	136	10,032
Running gear	72	7,568	8,373	650	16,663
Fittings	790	2,437	1,115	2,660	7,002
Total Engine	1,945	29,638	19,766	3,458	54,807
Tender	83	8,330	6,987	3,118	18,518
Total Engine and Tender	2,028	37,968	26,753	6,576	73,325

To which is to be added, for weight of engine in working order, for contents of boiler, fire-box, and two men in cab, about		6,000
And for contents of tender, coal	8,000 lbs.	
water (1600 galls.)	13,500 "	
		21,500
Giving for total weight of engine in service		60,807
And for total weight of tender		40,018
Approximate total engine and tender in service		100,825

No. of separate pieces, large and small (not including nails): In engine 4,904; In tender 1,366; Total 0,270

The proportion of brass is now, in general practice, much less than in the above engine.

TABLE 135.

LENGTH OF SERVICE, MILEAGE, AND LIFE OF LOCOMOTIVES ON PENNSYLVANIA RAILROAD (P. R. R. DIVISION) TO JANUARY 1, 1885.

Passenger Locomotives.

Years in Service.	Number of Locomotives. Total.	In Service.	Condemned.	Total Mileage (1 = 1000 miles). Highest.	Lowest.	Average per Loco.	Average Miles per Loco. per Year.
8......	2	2	0	382	344	363	45.372
9......	7	7	0	345	248	302	33.566
10......	3	1	2	294	264	282	28.165
11......	8	7	1	389	247	316	28.702
12......	6	3	3	563	307	391	32.573
13......	3	1	2	428	319	369	28.349
14......	11	9	2	613	286	401	28.657
15......	7	7	0	589	397	483	32.204
16......	9	8	1	780	351	491	30.689
17......	5	4	1	688	431	536	31.519
18......	4	3	1	637	488	559	31.067
13......	65	52	13	780	247	412	31.707

Freight Locomotives.

Years in Service.	Total.	In Service.	Condemned.	Highest.	Lowest.	Average per Loco.	Average Miles per Loco. per Year.
5......	33	33	0	197	130	161	32.263
6......	23	23	0	220	147	176	29.391
7......	10	10	0	279	192	250	35.705
8......	13	13	0	289	240	262	32,715
9......	27	24	3	314	225	273	30.349
10......	15	11	4	317	201	260	25 973
11......	12	7	5	416	202	287	26.063
12......	43	29	14	454	206	302	25.172
13......	44	32	12	440	235	318	24.425
14......	36	15	21	426	244	339	24.215
15......	26	14	12	561	271	378	25.204
16......	21	12	9	532	271	392	24.529
17......	16	8	8	485	324	397	23.337
18......	17	12	5	430	308	371	20.620
19......	2	0	2	400	351	375	19.758
20.....	4	1	3	519	378	438	21,905
21......	3	1	2	464	354	393	18,733
22......	4	0	4	431	387	411	18,684
13½.....	349	245	104	561	130	301	22,331

The above locomotives were intended to give a fair average of engines of all ages and classes of service, and cover about 60 per cent of the whole number in service. The locomotives having the highest mileage (780,182 miles, passenger; 561,139 miles, freight)

were both still running and in good order. In the original abstract the miles run were given to units, but have been abbreviated to the nearest thousand.

Running of engines first in first out was first introduced in 1878, six years before date of table, and abnormally increases the average mileage of the younger engines relatively to the older. Allowing for this, there is little evidence of diminution of yearly mileage with age.

SPECIAL PERFORMANCES.—*Engine* 273, 479,248 miles in ten years; $8336.42 for repairs, or 1.74 cents per mile run; 251,552 miles before being off its wheels for general repairs. *Engine* 274, 504,301 miles in ten years; $6534.45 for repairs, or 1.29 cents per mile run; 243,476 miles before being off its wheels, except once as the result of an accident. *Engine* 1047, 41,510 miles in three months, or 461 miles per day.

	Highest.	Lowest.	Average.
Average mileage of 72 passsenger engines, 1882, ...	79,258	30,039	45,936
" " 175 freight engines, 1882, ...	58,711	30,000	36,584

About 80 or 90 per cent of the breakages of the working parts of engines on the Pennsylvania Railroad occur immediately on starting from a stop.

A paper before the German Society of Mechanical Engineers showed that out of 39 engines (presumably a fair average)—

10 of shortest life were broken up after	6.5 years.
10 of longest life were broken up after	28.5 "
15 were in use less than 20 years, and average of all was	20.2 "

The average mileage of German locomotives (Table 69) is 11,870 miles per year, indicating a very short locomotive life in miles.

TABLE 136.

APPROXIMATE LIFE OF VARIOUS PARTS OF THE LOCOMOTIVE.

PART.	Authority.	Life in Years.	Life in Miles.
Locomotives as a whole, American........	M. M., L. S. & M. S. Ry.	22 to 24	700,000
" " " English (and Europe generally)...	R. P. Williams.........	20	450,000 to 500,000
Tenders, Tanks..................	L. S. & M. S. Reports....	10	800,000
" Frames, wood..................	M. M. Association..	7	250,000
Boilers, as a whole (*ex* partial renewals)	L. S. & M. S. Reports....	...	800,000 to 1,000,000
" English (prob. an av. of all parts)	McDonnell, M. Inst. C.E.	10 to 14	320,000 to 350,000
" U. S. " " " "	M. M., L. S. & M. S......	15	450,000
" " (bad water)..................	Various sources..........	....	300,000 to 350,000
Fire-box steel, bituminous coal fuel (wood, two thirds greater)..............	M. M., L. S. & M. S......	6	180,000
Fire-box steel, anthracite coal (iron or copper fire-box, about one third only)..	M. M., Ph. & Reading...	....	120,000
Fire-box steel (*anthracite* fuel, 50,000 miles less, passenger).......	M. M. Association........	10 +	300,000
Fire-box steel (*anthracite* fuel, 50,000 miles less, freight).........	M. M. Association.... ...	8 +	250,000

Bad water estimated to reduce these last averages about 100,000 miles, and increase cost of maintenance $750 per year, or $2\frac{1}{2}$ to 3 cents per mile run, in extreme cases. The L. S. & M. S. is an unfavorable road in this respect. **Fractures** of fire-box sheets, range as an average of 3 years (M. M. Ass'n Reports) over 1000 engines per annum, about *one sheet for* 10 *engines* per year on roads with bad water, and thence down to none with pure water. Lowest mileage of fractured plates, 75,000; highest, 150,000. Occurs only after deposit of scale. Nearly all fractures (about seven eighths) are in side sheets, vertical, starting just above fire.

Washing out boilers.—Good water, England, every three weeks. U. S. average, about one month, but much oftener with bad water. *Thickness of steel*, almost universally: tube-sheet, $\frac{7}{16}$ to $\frac{1}{2}$"; sides, back, and crown, $\frac{5}{16}$"; barrel, $\frac{3}{8}$".

		Years.	Mileage Life.
Fire-boxes copper.—Gt. No. and L., S. C. & D. Rys., English (pass. and freight)..	McDonnell...............	3 to 5	74,000 to 161,000
Tubes, iron, various English railways....	McDonnell...............	6 to 7	120,000 to 167,000
" " *entirely new sets*............	10 yrs., L. S. & M. S. Reps.	15	360,000

Ordinarily taken for entirely new sets at half the life of the engine, with one or more piecings at end in addition, and removal once in 1 to $1\frac{1}{2}$ to $2\frac{1}{2}$ + years, according to water, for removing scale. On Boston & Albany, with very good water, tubes are never removed nor boilers blown out except for repairs. Other lines, once in 6 to 8 years. *Brass tubes* not essentially different; require cleaning less frequently.

	Mileage Life.
Tubes, *brass.*—Average of English returns, passenger, fair water (freight about one half only)........	200,000
Maximum reported (McDonnell, average of 10 years)........	290,000 to 437,000
Axles, *iron* (*drivers*).—L. S. & M. S. and J., M. & I. (max. before removal)..	300,000
" " (*crank*).—English........	150,000 to 225,000
" " truck.—L. S. & M. S........	100,000
Bearings (*drivers*).—Various railways, per $\frac{1}{16}$" wear........	30,000 to 56,000
Highest report, D., L. & W., 89,000; lowest, Philadelphia & Reading, 14,000.	
Tires, *steel.*—5' 6" average of U. S.; 65,000 per turning; 3 turnings........	200,000
In heavy service, with small drivers, near about half this, or........	100,000
English reports very nearly the same, viz. 6' 6"........	196,600
English reports very nearly the same, viz. 4' 6"........	106,000 to 150,000
Driving-wheel centres.—L. S. & M. S. Reports........	2,000,000
Cylinders.—Same as engine.	
Frame.—" A question of accident" (M. M. Assoc.).	
Truck-wheels.—(About av. of U. S., 28" to 30" wheels). M. M., Ph. & Rdg.	34,000
Tender-wheels.—(About average of U. S., 33" wheels)........	50,000 +
Valves.—Common slide-valve between facings (M. M. Assoc.)........	30,000
" —Good balanced, several patterns, between facings (M. M. Ass'n)....	75,000 to 100,000
Scrap Value, old English locomotives (copper fire-box, brass tubes), about 10 p. c. of original cost of materials.	

The locomotives of the Pennsylvania Railroad go into shop for general repairs once in 18 to 20 months.

TABLE 137.

MISCELLANEOUS EXTRA HEAVY LOCOMOTIVES.

(A list published in the *National Car-Builder.*)

ROAD.	KIND.	WEIGHT. Total.	WEIGHT. On Drivers.	Drivers.	Cylinders.
Passenger Locomotives.					
Reading............	Fast express...........	96,200 lbs.	* 64,250 lbs.	68 in.	21 × 22 in.
Pennsylvania	" Class K...	92,700 "	* 65,300 "	78 "	18 × 24 "
Baldwin Loc. W'ks.	"	85,000 "	† 35 to 45,000 lbs.	78 "	18 × 24 "
Boston & Albany...	"	80,000 "	† 56,000 lbs.	66 "	18 × 22 "
Pennsylvania	Tank locomotive......	§ 120,400 "	....	60 "	17 × 24 "
Freight Locomotive.					
Reading	Consolidation.	102,000 "	88,500 lbs.	50 "	20 × 24 "
"	Twelve wheels coupled	101,000 "	101,000 "	46 "	20 × 26 "
A., T. & Santa Fé..	Consolidation, tank....	‡ 115,000 "	‡ 100,000 "	48 "	17 × 24 "
Central Pacific.....	Mogul, tank...........	....	88,000 "	48 "	16 × 24 "

* On four wheels. † On two wheels. ‡ Estimated. § Reported weight.

THE RUNNING GEAR.

504. The distinctive peculiarities of the running gear of American locomotives, as compared with foreign, are two: the swivelling TRUCK in front (in England called "bogie"), and the EQUALIZING LEVERS by which the load is kept uniformly distributed on the four or more drivers, and the effect of any chance irregularities in the track reduced to a minimum. The first was invented by John B. Jervis in 1830, soon after the trial of the Rocket took place; the second was invented by Ross M. Winans, who also invented the double-truck railway car which has become all but universal in this country, only a few years later.‖

505. Both of these inventions, with much else that was novel and meritorious, had their origin in the necessities of the earlier years of American railways, which required that the locomotives should be adapted to ready passage over sharp curves and imperfectly surfaced track and road-bed. Both of them are now gradually making their way

‖ A crude form of double-truck car was shown to have been used in Quincy, Mass., before Winans invented it, so that Winans was unable to support his claim for patent; but he reinvented it independently, and really deserves the credit for conceiving of and introducing it as the normal type of car. The equalizing lever has been claimed as the invention of Mr. Thomas Rogers, who probably was an original inventor, but Winans seems to have antedated him.

[illegible]

[illegible] with exceptions that prove the rule.

806. The original type of American locomotive, still distinctively [illegible] as the "American" type, has two drivers coupled, spaced 8 ft. to 8 [illegible], with the fire-box between them, with a four-wheel truck [illegible]. Until about twenty years ago this type was all but universal in both passenger and freight service, but the same is now rapidly [illegible].*

807. At the present time there are the following types in common use in America:

1. American [illegible] Table [illegible] 4 drivers, 4 truck wheels; still approved for light service, but passing out of use for ordinary freight and heavy passenger service.

2. Mogul [illegible] Table [illegible] 6 drivers, 2 truck wheels (pony truck); one of

* Complete illustrations of every detail of the ordinary form of "American" engine, with outline drawings of others, may be found in the "Catechism of the Locomotive," by M. N. Forney, and drawings and descriptions of many examples of all the types of locomotives here named in "Recent Locomotives." Both published by the *Railroad Gazette* of New York. The catalogues of the Baldwin and the Rogers Locomotive Works also contain views and many of the details of all ordinary types of locomotives, with much other interesting matter. All the above works are valuable ones for the engineer to own.

the earliest modifications of the "American" locomotive and largely used, but in rather less favor than formerly.

3. TEN-WHEEL (Table 128), 6 drivers, 4 truck wheels; generally preferred to the Mogul, and at one time bidding fair to become the standard type for heavy freight service, but now hardly tending to multiply, except as a substitute for the American for heavy passenger service.

4. CONSOLIDATION (Table 129), 8 drivers, 2 truck wheels; a comparatively recent innovation, invented by Alex. Mitchell, superintendent of the Lehigh Valley Railroad, in 1872. It has very rapidly won its way into public favor, and is now, it is hardly too much to say, the standard American locomotive for heavy freight service, and is fast coming into use for all but the lightest service.

These are the only types which can be said to be in general use for road service, but in addition there are the following in approved but more limited use:

5. MASTODON (Table 130), eight drivers, four truck wheels a very recent design introduced by Mr. A. J. Stevens, of the Central Pacific Railroad, in 1881, and said to be rendering most excellent service. Some have been built for the Lehigh Valley. It has not as yet (1886) been introduced to any extent on other roads, but it is exceedingly probable that it will be. While not very largely increasing the load on the drivers, which is not feasible, the four-wheel truck and greater load thereon not only makes the engine run better, but enables the boiler to be enlarged.

6. FORNEY, a type invented by Mr. M. N. Forney some twenty years ago, having the tender and engine combined on one frame, the tender running in front and its truck serving in lieu of an engine truck, so that the weight of the engine itself is carried wholly on the drivers.

508. The advantage of the Forney type is that it gives more tractive power (adhesion) for the same size of engine, by placing the entire weight of the latter on the drivers. Its disadvantage is that the boiler of no locomotive engine can generate steam enough to utilize its whole weight for adhesion, unless at slower than ordinary freight speeds, or in service requiring very frequent stops, as will be seen from par. 551. For such service only is the engine well adapted, and for such service only has it come into use. As this service is the exception, the quite extensive use which the type has recently been given still leaves it an exceptional type. It has been urged for use in general service, but is not well adapted for it in the respect mentioned.

509. Other types of engines are:

7. DOUBLE-ENDER, with two "pony" trucks, one at each end, or

sometimes with one "pony" and one four-wheel truck; used chiefly for short-run local service.

8. TANK ENGINES; a type not confined to any especial form of running gear, but available for any locomotive, whenever it is desirable to have very great adhesion for short runs. As this adhesion can only be utilized at very slow speeds, without exceeding the boiler power, there is no economy or advantage in placing a tank on the engine, except as a temporary resource, unless for very slow speeds; and hence, naturally, very small drivers, carrying nearly the whole weight of the engine, are usual with tank engines.

510. This type, carried one step further, results in—

9. FAIRLIE ENGINE; two boilers placed back to back with a single frame, and carrying on their back the entire supply of both fuel and water. The two "trucks" on which the whole is carried are driving-wheel bases, each carrying their own cylinders, which are supplied with steam through a swivelling joint. It is still less possible for engines of this type than for tank engines to utilize their great adhesion without exceeding their boiler power, except at the slowest speeds. Consequently they have only found acceptance for work on very heavy grades where great tractive power is necessary and slow speed no objection, and for such service only are they suitable. The type is the invention of the late Robert F. Fairlie, the "apostle" of the now moribund narrow-gauge movement, and was pushed by him energetically for many years, but without success, except as respects localities such as described (as for example the Mexican Railway described in Appendix C), where the type has done and is doing good service, although very costly to maintain.

511. Finally, in certain extreme cases, where still greater adhesion is necessary and still less speed desired, there is a device, already referred to (par. 495), by which the paying load is carried on a platform slung between two tank engines, and so utilized for adhesion, and when even these devices have not sufficed to give necessary adhesion on very heavy grades, reliance upon insistant weight to give necessary adhesion has been abandoned altogether, except as an auxiliary resource, and recourse had to other devices noted in par. 495.

512. In addition to the previous types mentioned, there are for yard use only—

10. FOUR-WHEEL SWITCHING ENGINES.

11. SIX-WHEEL SWITCHING ENGINES.

Both of these are made either tank or with tender, usually the latter. They are admirably adapted by their great tractive power for yard work, which

demands great power even for short trains, in order to get them under way easily, and they are only used for such service. Neither their boiler power nor running gear is adequate for high speed, and in fact engines with trucks are, as a rule, preferred even for yard service.

513. In all these various types the load on the drivers is equalized by side levers connecting the springs, whereas in foreign locomotives it is not customary to do more than give a separate spring for each wheel. The effect of this equalizing is that in all engines of the "American" type, and less perfectly in the other American types of engines, the locomotive is carried in effect upon three points, the centre of the truck and the centre of the equalizing system on each side of the boiler, in three-legged-stool fashion, which ensures perfect contact of wheel and rail, and uniform distribution of pressure, on all inequalities of track. For the same reason that a three-legged stool always stands solidly on any surface however rough, while one with four or more legs will only stand solid on a plane surface, the total weight is always evenly and fairly distributed between the wheels, however rough the track.

In foreign engines, on the contrary, which are not equalized, the consequence of this or some other and unexplained difference of detail or of administration is that there is very great irregularity in the pressure of the wheels on the track. The exhaustive experiments of the late Baron von Weber on maintenance of way showed the pressure on the rail varying all the way from zero to twice the average load. That the elimination of this irregularity of load by adding equalizers should have a certain effect to increase the tractive power seems reasonable, and that or other cause (perhaps only greater effort to utilize to the utmost the power of the locomotive) has had that effect.

514. All the diverse types of engines for road service, both American and foreign, while differing in almost every other detail of their running gear, agree in this—that in every case (except four- and six-wheel switching engines) there is either a truck or some substitute therefor to perform the office of pilot for the driving-wheel base. Experience has abundantly shown that such a pilot is necessary for safety at high speeds, or on rough track, and advantageous at all times. The different methods for accomplishing this end, in the order of their introduction, are as follows:

1. *A fixed axle*, parallel with the driving-wheel axle, but carrying a lighter load; the normal foreign type.

2. *The ordinary American four-wheel truck*, consisting of four wheels on two parallel axles, the whole swivelling on a centre-pin *O*, Fig. 102.

3. *The same truck with a swing motion*, the mechanical details of which are in substance similar to Figs. 101, 103, permitting the truck to deviate somewhat, laterally, from the axis of the driving-wheel base, as *Oa*, Fig. 100.

4. *The "pony" or Bissell truck* (so named from its inventor), consisting of only a single pair of wheels on a single axle, but with its axle attached to a radius bar (constructed in practice as a double V-shaped bar, as shown by the solid lines) so that the pair of wheels swivel around a point *O*, Fig. 98, 6 to 8 feet in the rear, thus having the effect to compel the single axle to always remain parallel with the driving-axles on tangents, while permitting it to assume a radial position on curves.

FIG. 98.

515. All these four plans have approximately the same object, to relieve the driving-wheel flanges of the task of guiding the driving-wheel base on curves, and to leave them only the simpler duty of holding them on the rails against the effect of chance irregularities of motion. To do this, if it be effectually done, it is plain that a heavier duty must be thrown upon the flanges of the forward wheels than properly appertains to the load carried on them, and apparently these diverse plans will accomplish the end with very unequal degrees of efficiency, and cause very unequal derailing moments in the forward wheels. Nevertheless, each and all of them have been approved by experience as adequate for the end in view, nor has experience shown any very great difference in the coefficient of safety of each. By investigating theoretically the mechanics of the locomotive-wheel base, we shall see why this should be so, and at the same time gain an important insight into the feasibility of using various types and sizes of locomotives on different alignments. The result of such an analysis, which follows below, is presented in Fig 107, page 433.

516. The work to be done by the pilot-wheels is in all cases the same—to prevent the front outer driving-wheel flange from grinding against the rail and compel it to stand away from the rail, or at least relieve its pressure. To do this, force or pressure must be applied at some point on the axis of the driving-wheel base sufficient to cause it, in effect, to continuously rotate; because it

compels the wheel-base to change its direction to follow the curve sooner than it naturally tends to do so.

The force (pressure) in pounds necessary to cause this rotation is the same, however fast or slow the motion of rotation takes place (the work done in foot-pounds per second only varying), and varies only with (1) the load on drivers, (2) the coefficient of friction, which, for reasons we shall shortly see, we will take at one third, and (3) the length of the wheel-base. The rotation may take place either by throwing the front axle inward or the rear axle outward, or both, but without going into unnecessary and doubtful details as to which is most probable, which would but little affect the final result, the resisting moment of the driving-wheel base to rotation may be estimated as follows:

TWO-AXLE DRIVING-WHEEL BASE, of length $= l$ and total load $= W$; letting $r =$ diagonal distance from centre of wheel-base to each wheel:

Resisting moment $M = Wr \times$ coefficient of friction (say $\frac{1}{3}$).

THREE-AXLE WHEEL-BASE, of length $= l$ and total load $= W$:

Resisting moment $M = (\frac{2}{3} Wr + \frac{1}{3} Wr') \times$ coefficient of friction.

FOUR-AXLE WHEEL-BASE:

Resisting moment $M = \frac{1}{2} W (r + r') \times$ coefficient of friction.

The values of r and r' are readily computed from the gauge and the length of wheel base.

This resisting moment is overcome in any form of locomotive-wheel base by a force applied at some point O, Figs. 98, 100, acting with a leverage, which let $= L$, varying with the pattern of engine; and the amount of this force, O, is readily determined by the formula

$$O = \frac{M}{L}$$

517. This statement of the action of these forces is incomplete in this, that a motion of rotation of the driving-wheel base can only be produced by the action of a COUPLE, and not by any single force. Actually, therefore, it is essential that one or the other wheels should serve as a fulcrum, to enable the force O, Fig. 99, by which the truck causes the driving-wheel base to rotate, to act; but which wheel it would be, or whether it would be any one single wheel for more than a few instants at once, we cannot assert with certainty, nor would the action or

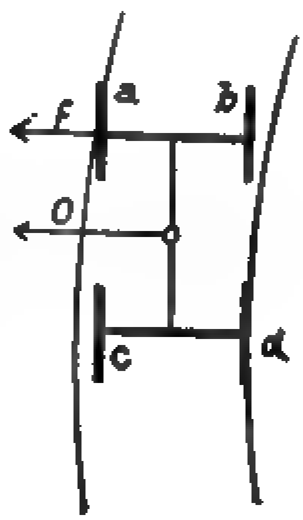


FIG. 99. FIG. 100.

amount of the force O be very greatly affected by any possible differences in this respect.

In the English type of wheel-base, three parallel axles, the two rear being driving axles, this force O is of necessity all supplied by the flange of the outer leading-wheel. In the American type of wheel-base, Figs. 99. 100, it is of necessity all supplied by the centre-pin of the truck; but it is to be remembered, as respects the wheel-bases with more driving-axles, like Fig. 98, that it is not essential that the driving-wheel flanges should be wholly relieved of all work in guiding the wheel-base, but only that they should be so greatly relieved that such flange pressure as remains to them shall not be injurious.

518. The lateral force at O, Figs. 98, 100, being given, the more important question remains—the amount of additional lateral strain thrown by it on the leading wheel a, Fig. 99. In every locomotive, as they are actually constructed, this wheel is in most danger of mounting the outside rail on curves. The flange pressure of this wheel may be determined as follows:

In the American type, Figs. 99, 100, the action of the forces on the leading truck is as follows:

As a result of guiding the truck itself, considered as a separate vehicle, the reaction of the rail against the front outer flange a must be enough, as we have seen (par. 302), to cause three of the wheels, a, b, c, Fig. 99, to rotate around d as a centre; or, calling the load on each truck-wheel w, and the coefficient of friction $\frac{1}{4}$ (instead of $\frac{1}{5}$, as for the driving-wheel base, on account of the lighter load), we have for the force f, Fig. 99,

$$f = \tfrac{3}{4}w.$$

The wheel c normally stands away from the rail, as shown in Figs. 99 and 20, and resists being crowded up against the outside rail with a force $= f =$ enough to slide the three wheels b, c, d.

519. The force O is equally divided between the two axles ab and cd, Fig. 99, so that we have, in any engine truck of an American engine:

Pressure of leading wheel a, Fig. 99, against outside rail $= \frac{1}{2}$ force $O +$ force f.
Pressure of rear wheel c against outside rail $= \frac{1}{2}$ force $O -$ force f.

The latter is true because the force f on the rear axle is a negative or resisting force. If $\frac{1}{2}O$ be greater than f, the wheel will be crowded up against the rail, but there will always be a force $= f$ tending to cause it to leave the rail, so that the net pressure against the rail will be only the difference between the two forces.

520. When the truck is a swing-motion truck the distribution of the forces is in no way affected. A certain amount of lateral motion takes place first—that is all—sufficient to bring about the equilibrium of forces sketched in Fig. 101, as one might take out the slack of a chain before it comes to a bearing, and then the force O acts as before.

Right here we touch upon the leading theoretical, and in fact practical,

objection to the swing-motion truck, although its true cause is not always appreciated. We have seen (par. 516) that the force *O* is a constant, regardless of the radius of curvature. Consequently, whenever this force is called into action at all, the same amount of lateral deflection, *Oa*, Figs. 100, 101, 102, will take place, or tend to take place, unless stopped by the driving-wheel flange coming in contact with the rail, which it is the object of the truck to prevent.

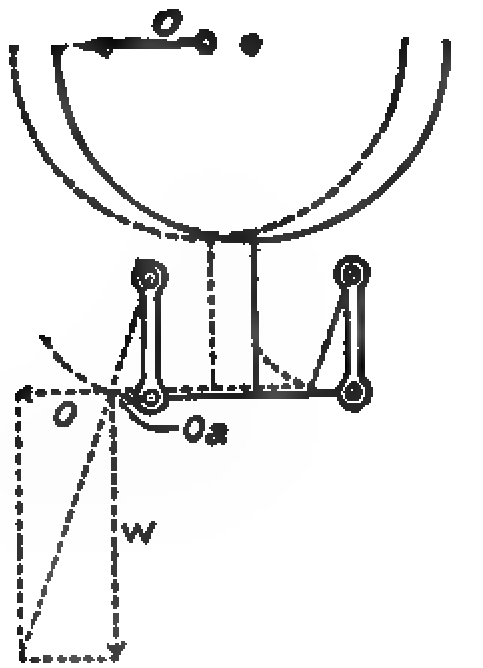


FIG. 101.

FIG. 100.

521. This is not at all what is desired, since it correctly adapts the wheel-base to motion on only one curve, that, namely, on which the distance *Oa*, Fig. 102, = the offset to the curve at *O* from a tangent to the curve at *c*. This must be on a comparatively sharp curve if the very object of the swing-motion (to enable the locomotive to pass sharp curves easily) is to be attained. On easier curves the amount of deviation which the swing-motion permits is as much too great as that of the fixed centre-pin is too small. On all easier curves the wheel-base will tend to assume a position something like Fig. 102, which is still less favorable than the normal position of an American engine wheel-base, without the swing-motion, outlined in Fig. 100. It is true that, owing to the splay given to the links of the swing-motion, there is a certain amount of resistance to any lateral motion, however slight; but this is not sufficient to restrain the tendency to assume the position shown in Fig. 101, and hence has little remedial effect.

522. For these reasons the swing-motion, although very largely used, has never shown the advantage over the fixed centre which it probably would if the lateral deviation were in fact proportioned to radius of curvature, as it is often assumed to be. As originally designed by Mr. Bissell (for "pony" trucks) it was not open to this objection; two inclined planes being used, in the manner shown in principle in Fig. 103, which offered the same lateral resistance however much or little motion took place. But for practical reasons (rapid deterioration of bearing surfaces and impact when bearings return to the centre) this form has passed out of use, perhaps in part for lack of giving due weight to the theoretical advantages which it undoubtedly possesses.

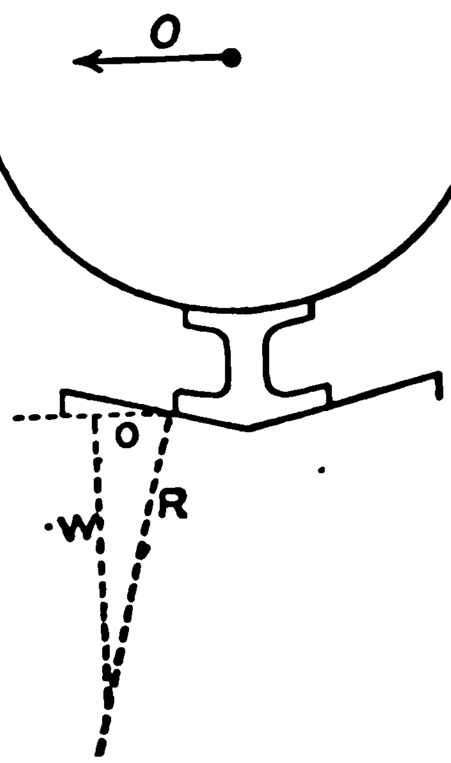


FIG. 103.

523. The manner in which the two-wheeled Bissell or "pony" truck (Figs. 104, 105) relieves the driving-wheel base of lateral strain is quite different, and much less clear. Apparently it ought not to assist at all, except to the very slight extent (especially on easy curves) by which the resistance of the swing-motion (Fig. 101), which is directly over the axle, resists lateral motion; for it is free to swivel around its bearing at O (Figs. 104 and 98), regardless of the remainder of the wheel-base. It is known to have in fact, however, a very material effect upon the motion of the wheel-base, and theory very readily indicates to us why this should be.

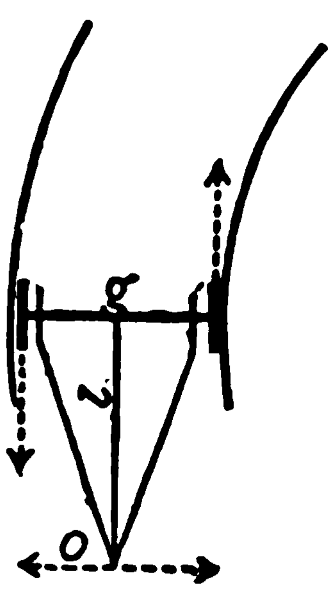


FIG. 104.

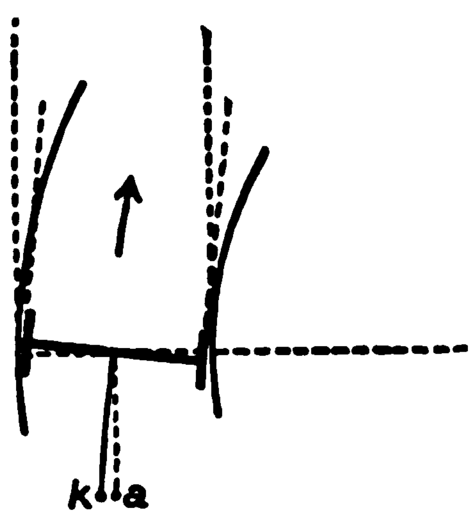


FIG. 105.

The "pony" truck naturally tends to roll forward in a right line, parallel to itself, as in Fig. 104. The rigid driving-wheel base behind, and not its own flange or its coning, as we shall see, compels it to move in a curve, to do which the driving-wheel base must exert a stress, O, Fig. 104, in the opposite direction to the arrow, of sufficient magnitude to produce motion in the direction *ak*, Fig. 105, and thus slide one or the other of the wheels continuously on the rail, compelling the leading axle to move in a curved path instead of a straight one. The resistance of the wheels to this sliding creates one or the other (not both)

of the two forces represented by the longitudinal arrows in Fig. 104, and for the force O, resulting therefrom, we have

$$O = (\text{load on one wheel} \times \text{coef. frict.}) \times \frac{g\ (\text{Fig. } 104)}{l\ (\text{Fig. } 104)}.$$

524. Lest the wheels should run toward the outside rail, and from coning or otherwise adapt their diameters to naturally travel in a curve, we have this further precaution:

To enable both the pony truck and the transverse axis of the driving-wheel base to assume radial positions, the radius-bar of the pony truck should, from well known properties of the circle, pivot at the point O (Fig. 106), midway between c and the "pony" axle. If shorter than this, as at o, Fig. 106 (as it always is), the driving-wheel-base will throw the rear end of the radius-bar over through a certain distance (ak, Fig. 105) toward the outside rail, and thus create in it a tendency to run toward the inside rail and away from the outside rail. This tendency is increased by the fact that it is the rear and not the centre of the driving-wheel base which tends (par 294 and Fig. 20) to assume a radial position, the front outer driving-wheel tending of itself to crowd hard against the outer rail.

525. These two causes together ensure that the pony axle shall always have a continuous tendency to run toward the inside rail and away from the outside, and if the radius-bar be made too short this tendency becomes so decided that injurious wear results. Thus, in a Consolidation engine of the Norfolk & Western Railroad the radius-bar was originally only 4 ft. 2 in long, and created so strong a tendency to run to the inside rail that it was lengthened to 5 ft. 6 in. long, with very beneficial results. Even then the point O was some 9 ft ahead of the centre of the wheel-base, c, Fig. 106, so that it was still much shorter than was apparently required to enable the wheel-base to adapt itself most perfectly to the curve.

FIG. 106.

No very strong tendency in the pony axle to run toward the inside rail is necessary, but only just enough to ensure the driving-wheel base shall in fact modify its natural path in the way outlined, by however little, since if any force whatever (O, Fig. 104) needs to be applied to cause the pony axle to roll in the curve it must necessarily be adequate to slip the wheels on the rails: the stress necessary to slip them a little is as great as to slip them a good deal.

From this it will be seen that if $l = g$ (Fig. 104) the lateral force at O necessary to alter the path of the leading wheels is just *half* as great as if these were a fixed axle at O, in the English style (because there is only one wheel to slide instead of two), with the added advantage that the pony axle is approximately radial and guided by the wheel-base behind, so as to relieve the pony flanges of strain, and thus add greatly to safety.

In addition to the force O, Fig. 104, the swing-motion of the pony truck supplies any desired amount of additional lateral force, directly, whenever the engine is running on curves sharp enough to develop it fully.

526. For the forces acting on the leading outer wheel of any locomotive wheel-base, then, if it is in fact to perform the office of guiding the complete wheel-base on curves, we have these conditions: There is a vertical component equal to the load on the wheel, and there is a horizontal component equal to the forces determined for all the various types in pars. 516 to 525. These forces, as computed for a great variety of light and heavy engines of all types, have been plotted in Fig. 107, which represents graphically the comparative degree of safety of various types of locomotives for passing curves; and the surprising degree of uniformity which they show in a measure tends to confirm the correctness of our conclusions, since experience has shown that there is in fact no marked difference in safety between the engines themselves.

NOTE TO FIG. 107.—The diagram shows in magnitude and direction the resultant of the horizontal and vertical forces acting on the front outer truck-wheel of locomotive wheel-bases of all common types ON CURVES OF ANY RADIUS (the same being, except for unknown variations in the coefficient of friction, UNIFORM FOR ALL RADII).

The comparative safety may be considered as varying—

First. With the DIRECTION of the resultant, as being more or less inclined to the horizontal; those most inclined being the safest, other things being equal, since the resistance to the flange mounting the rails is then greatest.

Secondly, and chiefly. With the MAGNITUDE of the resultant, or total pressure of the wheel against the rail.

All American engines, embracing a great variety of designs and weights, will be seen to lie within the small quadrilateral marked out by the points 1, 3, 10, 15. The more common English types cause a far greater pressure against the rails, but as a compensating advantage have more nearly vertical resultants.

Details as to all the locomotives shown may be found either in "Recent Locomotives," Forney's "Catechism of the Locomotive" (Railroad Gazette), or Barry's "Railway Appliances" (Spon).

MANNER OF CONSTRUCTING THE DIAGRAM.

The vertical ordinates represent the load in pounds on the front outer wheel.

The horizontal abscissæ represent the lateral stress in pounds acting on the wheel, which consists of (*a*), with four-wheel trucks only, the flange pressure necessary to cause rotation in the truck, and (*b*) *half* the force O, Figs. 99 and 104, required to be applied at

the centre-pin of the truck (or all of it in the case of two-wheel "pony" trucks) to produce rotation of the driving-wheel base.

The various types of locomotives shown are:

Type	Locomotives
MASTODON. (4-wheel truck.)	1—Central Pacific. 2—Lehigh Valley.
CONSOLIDATION. (Pony truck.)	3—Baldwin. 4—Pennsylv'a (Class I).
TEN-WHEEL. (4-wheel truck.)	5—Baldwin. 6—Pennsylvania.
MOGUL. (Pony truck.)	7—Baldwin. 11—Heavy Mogul.
AMERICAN. (4-wheel truck.)	9—Baldwin. 10—Pennsylvania. 12—English fast passenger 14—Pennsylvania fast passenger. 15—Old (light) fast passenger.
ENGLISH. (No truck, leading axle.)	8—Freight type. 13—Passenger type.

TRACTIVE POWER.

527. The friction between the driving-wheels and rails which prevents them from slipping and enables them to propel the train is a STATIC or merely resisting friction, as distinguished from DYNAMIC friction, or that in which motion takes place between the surfaces in contact, with resulting destruction of energy. Its cause, beyond all question, is an absolute interlocking of the roughnesses or projecting fibres of the surfaces in contact, as cogs might interlock. That this is essentially true of all friction between metallic surfaces, under the most favorable circumstances, was curiously shown by experiments of Mr. Beauchamp Tower* on the most finely polished and completely lubricated journals: a mere change in the direction of revolution resulted in a noticeable but temporary increase in the coefficient of friction, for which so careful and competent an observer could ascribe no other cause than that the fibres were stroked one way by continuous revolution, as fur might be, and that on motion being reversed the fibres opposed each other.

528. Our best existing evidence, by far, of the general laws which govern static friction between rail and wheel is contained in two papers by Capt. Douglas Galton, giving the results of experiments on brake efficiency conducted by him and by Mr. Geo. Westinghouse in 1876. These experiments are quite unique in the completeness and accuracy of the apparatus used, and (what is still more important) in the thoroughness and technical knowledge with which the records were analyzed, and they positively contradict the assumption sometimes made, that the

* Trans. Inst. Mech. Engrs., 1885. See Appendix B.

coefficient of friction between rail and wheel is greater at low speeds "on account of less time for new surfaces to interlock." *

An impression that the adhesion is less at speed has been derived, in some instances, from dynamometer records, which shows far less tractive pull between stations than in starting. This, however, results merely from the fact that the cylinders are not able to exert their full power at speed, and has no real connection with the adhesion.

No error of moment can arise, therefore, from assuming that the resistance of the wheels to slipping is sensibly constant at all speeds. It is only at slow speeds that the precise amount of adhesion becomes important.†

That the coefficient of adhesion is the same at all train-speeds has not been experimentally proven; but however fast the motion of the locomotive, so long as the drivers do not slip, the adhesion is equally static; and the only reason why the adhesion should be less at high speeds is that the fibres are afforded less time to completely engage with each other. That this difference may have some slight effect is possible, but as the available cylinder power falls far more rapidly with increase of speed, it is a fact which is not important, even if true.

529. WHEN SLIPPING HAS ONCE BEGUN, however, the conditions are very different. Chiefly from the Galton-Westinghouse experiments before referred to, which are confirmed from other sources and by universal experience, we may derive the following conclusions as to the general laws which govern friction between rail and wheel; all of which correspond closely with the results of modern investigations of other kinds of friction.

* "The Pennsylvania Railroad Company," by James Dredge: Appendix on Brake Trials. The exact language of Capt. Galton on this point is:

"The amount of frictional resistance which determines the point at which the rotation of wheels is checked varies, it is true, in the different experiments. The ratio which it bears to the weight upon the braked wheels" varies from .29 to .35, averaging .25. "But it [the variations]clearly represents simply the adhesion between the wheel and the rail, and varies only with this, and not with the speed.

"Thus at 60 miles per hour the amount of frictional resistance which checked the rotation of the wheels was about 2000 lbs, exhibiting an adhesion of about .191 per cent; at 15 miles per hour, 2160 lbs. or .196 per cent. As these two values are so nearly equivalent, it would appear that the effort is much the same at all speeds."

† D. K. Clark, a usually careful authority, states (p. 724, "Man. Mech. Engr."). "As the speed is increased the adhesion is reduced," as a result of his own tests of locomotives. The author cannot but believe, however, that this is an over-hasty conclusion by that able and usually trustworthy writer.

1. The coefficient of static friction between rail and wheel is not sensibly affected by the velocity of motion (as above).

2. It is very greatly affected by the insistent weight, increasing rapidly therewith.

3. It is very greatly affected by the condition of the surfaces as respects moisture or other equivalent for a lubricant, even when the eye can detect no difference, and is very considerably affected by unknown causes, so that it can rarely be determined twice alike.

4. It is greatest when the rails are very dry or (probably for the reason that the minute mineral and metallic particles which act as rollers are washed away) very wet, moisture or frost having the most injurious effect.

5. The coefficient of dynamic or sliding friction is very greatly less than static friction, and very greatly affected by velocity, in inverse ratio thereto. At the instant when slipping begins, the velocity of the rubbing surfaces being very small, it is sensibly the same as static friction, but as the velocity becomes greater it falls very rapidly, until it is hardly one third or one fourth as great as the static friction.

Tables 112, 113, page 290, show the general results of these tests, and the evidence on which the above conclusions are based, more clearly than words.

From these laws it necessarily results that when slipping of the drivers once begins the resistance to further slipping (coefficient of friction) should almost instantly fall, and hence that the wheels should almost instantly begin to "spin;" i.e., the surplus energy of the drivers, no longer required to turn the wheels against a great resistance, but only against a small resistance, must necessarily go somewhere, and is stored in the wheels in the form of velocity, sometimes making them "spin" so violently (when steam is not shut off soon enough) as to wear holes in the rails one-eighth to one-half inch deep. This spinning is not an evidence of overloading, since (par. 483) in any well-designed engine letting in the full power of the cylinders will in any case give a greater tractive energy than the wheels can transmit. The proper course when it occurs is to shut off steam, let the drivers come to rest, and start more gradually. If engines are to be loaded up to their full capacity, only the greatest care can prevent this phenomenon occasionally occurring, and it does occur constantly in practice, in starting trains, although rarely when in motion, except when the train is almost at a stand-still.

530. A long list of actual performances of locomotives in service is given in Table 138, and from this and the further data

below it is clear that the following average coefficients of adhesion may be assumed with sufficient exactness as corresponding closely to the results of American practice. European practice (par. 537 and Table 139) shows much lower ratios of adhesion :

	Min. (load on drivers = 1.00).
1. Ultimate limit of adhesion in practice, under conditions in all respects favorable, and with loads per wheel exceeding 10,000 lbs., . . .	0.35 to 0.37
2. Working limit of adhesion when sand is used, .	(1/3) 0.33
3. Working limit of adhesion in ordinary summer weather, and maximum limit with loads of less than 10,000 lbs. per wheel, ...	(1/4) 0.25
4. Working limit of adhesion on slightly moist or frosty rail, being the apparent average of adhesion which limits the weight of trains in winter (as to which see par. 632), ...	(1/5) 0.20
5. AFTER THE WHEELS HAVE ONCE SLIPPED, the coefficient rapidly falls (see Table 112) to less than	(1/10) 0.10

531. The first of these limits was realized by Zerah Colburn as early as 1853, and with light locomotives (10,000 lbs. per driver), in his still famous tests on the Erie Railway, and repeatedly since. In a large number of recorded instances trains have been hauled in regular service which demanded nearly or quite one third adhesion, but only as exceptional performances. A long list of notes as to such trains might be given.

532. The second limit (when sand is used) is less fully determined, but various dynamometer records of the effect of sand to increase tractive power indicate that it increases the working limit of coefficient to about 1/3 under all conditions of track or weather; that is to say, it makes the adhesion on a bad rail as high as on a good one. On a good rail it does not appear that the coefficient of adhesion is appreciably increased, but what is gained by the sand is to retard the tendency to slip. Direct evidence on the subject is scarce, and there is no doubt a

TABLE

PERFORMANCE OF AMERICAN

(Including all the Records of Performance given

AMERICAN

No. of Record.	Cylinders. Inches.	Weight of Engine. [All Tons, 2000 lbs.] Engine.	Tender.	On Drivers	Tractive Power, at ¼ Adhesion. Lbs.	Character of Performance.	Grade, Feet Per Mile.*
1	13 × 22	28.0	24.0	17.5	8,750	Single performance	72 + 2
2	"	"	"	"	"	" " "engineers say."	"
3	14 × 22	29.5	24.5	19.0	9,500	Regular (?)	52.8
4	"	"	"	"	"	Single perf. "with ease."	71.0
5	15 × 22	31.0	25.0	20.0	10,000	Regular service	237.0
6	16 × 24	33.0	25.0	21.5	10,750	" "	42.0
7	"	"	"	"	"	" "	65.0
8	17 × 24	35.0	25.0	23.0	11,500	Second trip	47.7
9	"	"	"	"	"	Regular	70.0
10	"	"	"	"	"	"Frequently."	40 0
11	"	"	"	"	"	Regular (?)	63.9 + 2
12	18 × 24	37.0	26.0	24.5	12,250	"No difficulty."	160.0
13	"	"	"	"	"	"Can't exceed 10 m. p. h."	"

* The additions to the grade in this column are an allowance for

TEN-WHEEL

No. of Record.	Cylinders. Inches.	Engine.	Tender.	On Drivers	Tractive Power, Lbs.	Character of Performance.	Grade, Feet Per Mile.
14	16 × 24	36.15	26.0	27.1	13,550	"Have taken."	48 + 8
15	"	"	"	"	"	Pass. exceed 20 m. per hour	53 + 5
16	17 × 24	38.0	26.0	28.5	14,250	Single trip	77 + 3
17	"	"	"	"	"	" "	150 + 12
18	18 × 24	40.0	26.0	30.5	15,250	Maximum load	79 + 3
19	"	"	"	"	"	Regular "	"
20	"	"	"	"	"	"Daily and easily."	62 + 4
21	"	"	"	"	"	" " "	21 + 5
22	"	"	"	"	"	Maximum Load	126
23	"	"	"	"	"	" "	76
24	"	"	"	"	"	Usual load	126
25	"	"	"	"	"	" . "	76
26	19 × 24	42.0	26.0	32.0	16,000	"Have pulled."	76 + 6
27	"	"	"	"	"	" "	101 − 8

MOGUL

No. of Record.	Cylinders. Inches.	Engine.	Tender.	On Drivers	Tractive Power, Lbs.	Character of Performance.	Grade, Feet Per Mile.
28	16 × 24	35.5	25.5	30.0	15,000	"Equiv't work every day."	83 + 21
29	"	"	"	"	"	do. (gained speed in test)	40.5
30	"	"	"	"	"	Regular trains	53.
31	"	"	"	"	"	Irregular "	"
32	17 × 24	37.5	25.5	31.5	15,750	"Have hauled."	44 ±
33	"	"	"	"	"	" "	"
34	"	"	"	"	"	Largest regular load	70 + 6
35	"	"	"	"	"	Comparative test	85 + 10
36	18 × 24	39.0	26.0	33.0	16,500	"Equal serv. every day."	53
37	"	"	"	"	"	Intended as daily duty.	60
38	"	"	"	"	"	" " " "	70
39	"	"	"	"	"	Momentum grades. reg. ser.	53 − 21

138.

LOCOMOTIVES IN PRACTICE.

in the Catalogue of Baldwin Locomotive Works.)

ENGINES.

the effect of curvature, as noted below this table, on next page.

ENGINES.

14.	29.21	..	....	577.2	462	115	24 9%	Del., L. & W'n.
15	30.0	34	Eng., pass...	387 8	450	(−62)	(−13.7%)	Norway.
16.. ...	38 3	14	Heavy loads..	372	372	0	0	West. Md.
17	69 36		.. ....	207 4	205	2	1 0%	C & Fogelsv (Pa.)
18 . .	39 15	18	21 tons	452	389	63	16 1%	Youghiogheny.
19	"	15	"	410	389	21	5 3%	"
20	33 0	48	Empties.	496 3	463	33	7 2%	B., N. Y. & Phila.
21	17 85	40	Loads.... ..	945 2	855	90	10.4%	" "
22 .	55 73	.	... .	331 2	274	57	20.8%	Lehigh Valley.
23	38 79	..	....	448 8	393	56	14.2%	" "
24	55 73	..	.. ..	189 to 292	274	0	0	" "
25 ...	38 79	..	. ...	315.5	393	−77	−19 8%	" "
26	39 06	22	18 tons	472	409	63	15.3%	St. L. & San Fran.
27 . ..	43 23	22	"	472	370	102	27 8%	" "

ENGINES.

28.. ...	40 2	45	Empties....	390 4 395 8	373	17 23	5.4%	Sharpsville.
29... .	23 4	28	Load of coal..	573 3	605	0±	0	"
30 ..	28 0	21	Loads.	481	536	−45	−8 4%	Western Ala.
31 ..	"	25	"	561	536	25	4 7%	" "
32 ..	24 7	28	"	679	637	42	6.6%	T. H. & Ind'olis.
33 . .	"	9 45	Loaded ... Empties...	665	637	28	4.4%	" "
34	36 8	17	23 tons	452	428	24	5.6%	E. T., Va. & Ga.
35	44 0	37	9.5 tons	418 5	358	60	16 7%	E. Kentucky.
36 ...	28.08	28	Loaded	709	588	121	20 5%	F. & Père Marq.
37 ..	28 1	.	. ...	665	587	78	13 2%	Mo., K. & Tex.
38 ..	34 5	..	....	544.1	479	65	13.6%	" "
39......	20.12	40 45	Loaded ..	825 910	820	0±	0	C. & Talc. (Chili).

TABLE 138.—

CONSOLIDATION

No. of Record.	Cylinders. Inches.	Weight of Engine. Tons, 2000 lbs.			Tractive Power, at ¼ Adhesion. Lbs.	Character of Performance.	Grade. Feet Per Mile.
		Engine.	Tender.	On Drivers			
40	20 x 24	45.8	26.2	39.7	19,850	Regular service	0 + 6
41	"	51.0	26.0	44.0	22,000	" "	96
42	"	"	"	"	"	" "	145 + 10
43	"	"	"	"	"	do. (fair average work.)	116 + 10
44	"	"	"	"	"	" " "	64 + 28
45	"	"	"	"	"	Regular load	96 + 10
46	"	"	"	"	"	Occasional load	"
47	"	"	"	"	"	Trial trip	45 + 3
48	"	"	"	"	"	Daily service	171
49	"	"	"	"	"	Using sand	"
50	"	"	"	"	"	Regular service (?)	23
51	"	"	"	"	"	Maximum load	126
52	"	"	"	"	"	Usual "	"
53	"	"	"	"	"	Maximum "	76
54	"	"	"	"	"	Usual "	"
55	"	"	"	"	"	Maximum "	96 + 10
56	"	"	"	"	"	Usual "	"
57	"	"	"	"	"	Average of 5 years	96
58	"	"	"	"	"	" " "	130
59	"	"	"	"	"	Daily service	68.6
60	"	"	"	"	"	" "	67.6
61	"	"	"	"	"	" "	53 − 4
62	21 x 24	60.0	0.0	50.0	25,000	" "	105.6
63	"	"	"	"	"	" "	184.8
64	"	"	"	"	"	" "	316.8
65	"	"	"	"	"	Maximum	"

The caboose is included in the gross loads given when used on train, although not included in list of cars.

The assumed ratio of adhesion used in this volume (as also by the Baldwin Locomotive Works) is ¼. The percentage by which the calculated load taken from Table 170 exceeds or falls below the computed load may be estimated by the following:

An assumed adhesion of ⅓ would *increase* the calculated load 33⅓ per cent.
" " " " ⅕ " *decrease* " " " 20 " "

The principal cause of the fluctuations between the actual and computed loads, however, lies in the fact that the reported gradients are not the actual *de-facto* gradients for operating purposes, but are increased in effect, in some instances, by uncompensated curvature or stopping-points on the maximum grade, and diminished in others by the use of momentum to assist in surmounting them. No. 8 (Kansas Pacific) and No. 9 (M., K. & T.) are conspicuous instances of the latter, the loads reported as hauled being beyond all probability for *de-facto* grades of the given rate. Nos. 2, 4, 10, 11, 14, and 27 are probably less conspicuous instances of the same use of momentum to *practically* reduce grades below the profile rate. In Nos. 27, 39, 61 this was expressly stated to be the case, and (the length of the grade being given) the corresponding *de-facto* grade per mile was com-

Continued.

ENGINES.

No. of Record.	Resistance. Lbs. Per Ton.	Train-Load. Actual. No Cars.			Train-Load. According to Table 170.	Excess of Actual Load over Table. Tons.		Name of Road.
		No Cars.	Kind of Load.	Tot. l'd, inc.eng.		Tons.	Per Cent.	
40	11.0	82.0 / 90.3	Loaded	1720 / 1886	1804	0±	0	Ph. & Erie.
41	44.36	22	Loaded	438.4	496	−58	−11.7%	Dom Pedro II.
42	66.71	26	Empties	298.0	330	−31	− 9.4%	Tyrone Br., Penn
43	55.72	15	Loaded	405.2	394	9	2.3%	" "
44	42.85	40	"	478	513	−35	− 6.6%	Lehigh & Susq.
45	48.15	33	"	375.7	456	−80	−17.4%	Lehigh Valley.
46	"	35	"	393.7	456	−62	−13.7%	" "
47	26.18	47	"	1100	840	260	31.0%	Missouri Pacific.
48	72.8	32	Empties	264	302	−38	−12.6%	Cumb. & Penna.
49	"	..	...	309	302	7	2.3%	" "
50	16.71	100	Load, 4-wh.	1144	1320	−176	−13.3%	Central N. J.
51	55.73	35	4-wh., coal	445.5	394	52	13.1%	Lehigh Valley.
52	"	25	" "	340.2	394	−54	−13.7%	" "
53	36.79	140	Empty 4-wh.	610.1	600	10	1.7%	" "
54	"	100	" "	458.8	600	−141	−23.5%	" "
55	48.15	40	Load, 4-wh.	498.1	487	11	2.3%	" "
56	"	35	" "	445.5	487	−41	− 8.4%	" "
57	44.36	100	Empty 4-wh.	457.8	496	−38	− 7.7%	" "
58	57.24	30	Load, 4-wh.	392.8	384	9	2.4%	" "
59	34.14	29	15-ton load	752	644	108	16.8%	Chic., Burl. & Q.
60	33.76	30	" "	776	653	123	18.8%	" "
61	26.56	40	Loads	1005	828	177	21.4%	" "
62	48.	..	...	542.5	520	22	4.2%	Atc., T. & S. Fé.
63	78.	..	...	318.5	320	−1.5	0	" "
64	128.	7	Loads	210.5	195	16	8.2%	" "
65	"	9	"	254	195	59	30.3%	" "

puted and used in computations, the reduction being indicated by a — sign in the column of grades.

On the other hand, most of the instances in which the reported performance is less than Table 170 calls for are to be explained by high speed or by uncompensated curvature, except under Consolidation engines, where the character of the trains (chiefly 4-wheel coal cars) had no doubt equal or greater effect to diminish the load.

Curvature was assumed to add only 1 ft. per mile (0.38 lb.) per degree of curvature up to 10° curves, and 2 ft. per mile per degree for sharper curves, when expressly stated to constitute an addition to the grade, and this addition is indicated by the sign + in the column of grades. A very low rate was assumed in order that the comparison of actual and theoretical loads might be more certainly trustworthy.

From the above table we may conclude *that if the given grade be the de-facto grade for operating purposes, with all effects of curvature and velocity eliminated, an assumed* ADHESION OF ONE FOURTH *the weight on drivers and a rolling friction on tangent, at* 15 *miles per hour, of* 8 *lbs. per ton* (*the latter being somewhat more than ample*) *will give very approximately* THE SAFE OPERATING LOAD IN REGULAR SERVICE.

A long list of further records of performance the writer omits to save space. Quite a number of them show more than ⅓ adhesion realized as an average of long runs, but not as every-day performances.

certain deduction to be made from the apparent gain because of the increased tractive train resistance caused by the sand on the rails.

533. The third, and most important limit, that of ordinary working, is warranted by the all but universal evidence of modern experience, as sufficiently proved by Table 138, which gives a long record of actual performances with locomotives, taken chiefly from the very abundant data given in the catalogue of the Baldwin Locomotive Works, and including ALL the records therein. The ratio of $\frac{1}{4}$ is used by them as the basis for computing the table of capacity on various grades given in their catalogue, and thus in a measure guaranteed by them, and the high character and great experience of that firm entitles this fact to far more than the usual weight which would be accorded to manufacturers' evidence.

534. Many causes combine to make the apparent indications of practice very variable. One of the most important is that the nominal ruling gradient is not the real or "virtual" one, being in some cases higher than the virtual grade, because the ruling grades are short and surmounted in part by momentum; and in others (and far more commonly) lower than the virtual grade, because of the necessity of stops on unreduced gradients, or of unreduced curvature on the ruling grade, thus materially increasing the nominal maximum: so that if we assume the grades of the profile to be the virtual grades, the trains hauled will appear to be only such as are due to $\frac{1}{5}$ adhesion, or even less.

On very low gradients this is especially true; and, moreover, another cause comes in—the difficulty of starting, making up, and handling very long trains. From this it results that we very rarely indeed hear of trains being hauled on very easy grades such as are beyond all question within the power of the locomotive under conditions which are as fair actually as they are nominally. But when these errors are eliminated it will be found that in all cases, in good American practice, the actual ratio of adhesion is $\frac{1}{4}$, whenever it is attempted to load the engines to their full capacity.

535. The fifth ratio of adhesion, 1/6, apparently applies to winter loads, and will actually give, in most cases, the loads which are hauled in practice in winter. It is usually assumed that this difference is due to the fact that the ratio of adhesion is less in winter than in summer, but it appears probable that in reality, as we shall see (par. 632), it is due to an increase in the rolling friction, both because of greater axle friction and because of the poorer condition of the track.

536. In the former edition of this treatise 1/6 instead of 1/4 was assumed as the ordinary working ratio of adhesion. This was deduced

TABLE 139.

COMPARATIVE RATIOS OF ADHESION OF AMERICAN AND FOREIGN LOCOMOTIVES.

CONDITIONS.	RATIO OF ADHESION.	
	Foreign Engines.	American Engines.
Maximum at slow speeds and under favorable conditions	1/4 or 0.25	1/3 or 0.33
Working maximum	1/5 or 0.20 to 1/6 or 0.17	1/4 or 0.25
Ordinary apparent adhesion	1/7 or 0.14	1/5 or 0.20

Many European engineers assume 1/7, or even less; but many American engineers, in like manner, assume 1/4.

From a summary by Mr. O. Chanute, in "Haswell's Pocket-Book," we may abstract the following data as to early and European tests of adhesion:

		Ratio of Adhesion.
Mr. Wood on early English railways (perhaps the earliest tests on record)	Perfectly dry rails	0.14
	Damp or muddy rails	0.08
	Very greasy rails	0.04
B. H. Latrobe on B. & O. R. R. 1838	Safe working limit	0.13
Modern European practice	Maximum	0.20
	Minimum	0.11
	Sœmmering line	0.16
Italian Alpine road, subject to frequent mists	Maximum in open cuttings	0.12
	Maximum in tunnels	0.10
French experiments. 1862–67 by Messrs. Vuillemin, Guebhard, and Dieudonné	Dry weather	0.105 to 0.20 (0.155)
	Damp weather	0.132 to 0.139
	Wet weather	0.078 to 0.164
	Light rain	0.09
	Rain and fog	0.14
	Heavy rain	0.16

The last records are of dubious value. Mr. Chanute gives a table of average European and American practice, which differs somewhat from the above, but seems open to question in several details.

by comparison of the actual loads hauled on various nominal grades by the same engine. Besides the causes just mentioned, however, which tend to make this process inaccurate, within the nine years from 1876 to 1885 a very great change has taken place in the average train-loads hauled on American railways, as shown in Tables 30 to 33, and others. Much of this is due to the use of heavier engines, but a great part of it is due to greater care to load engines to their full capacity.

537. The adhesion of English and other foreign locomotives is ordinarily stated at less than of American by a considerable percentage. Table 139 approximates closely to the difference which appears to exist. How much of this represents an actual difference of capacity, and how much is due merely to difference of administration, it would be impossible to say; but there is no room for doubt of the fact that foreign engines haul lighter trains, as a rule, than American engines of the same weight, or that European engineers state the limit of their adhesion at less than that given by American engineers for American engines.

538. If we may assume that the loads hauled by the same engine on any two grades are affected only by the difference in the grades (which ordinarily we cannot, except very approximately), we may at once determine from the records of these loads the rolling friction and ratio of adhesion, as follows.

Let L and L' = the gross load (including its own weight) hauled by the same engine on any two grades, g and g'.

Let x = the total resistance per ton on the lowest grade g, and d = the difference in resistance per ton on grades g and g' (being that due to gravity only, and equal to the resistance from gravity on a grade of $g' - g$).

Then $$Lx = L'(x + d),$$

whence $$x = \frac{L'd}{(L - L')}.$$

Then we have

$$\text{Rolling friction} = x - \textit{resistance from gravity only on grade } g.$$

$$\text{Traction of engine} = xL$$

$$\text{Ratio of adhesion} = \frac{\textit{traction}}{\textit{wt. on drivers}}.$$

But while these formulæ are theoretically correct, results determined by them are to be accepted as reliable only with great caution. If the reported low-grade loads are too small, as they usually are, the effect will be to greatly increase the apparent rolling friction.

539. Owing chiefly to some misinterpreted experiments made in France

some years ago by a M. Rabeauf, a chief engineer of the *Corps des Ponts et Chaussées*, there has for some time been some available authority to show that there may be such a thing as "IMPERCEPTIBLE" OR CONTINUOUS SLIP in the driving-wheels of locomotives in motion. Such a thing is really impossible, but the impression that it occurs has become widespread, and mere assertions in support of it, or allusions to it as a well-known fact, exist without number. The experiments referred to, from which this whole imaginary discovery seems to have originated, were described in a paper in the *Annales du Génie Civil* (1876), in which the record was given of tests of a fast passenger engine for the Northern Railroad of France, having four coupled drivers 6 ft. 10 in. diameter, carrying 26½ tons on a grade of 0.5 per cent (26 ft. per mile), with good rail and weather, and 121 lbs. per square inch boiler pressure. The report continues:

"Under these conditions the locomotive, which was tested alone (hauling no train behind it), attained a speed on the down grade of 74½ miles an hour, corresponding to 303 revolutions of the drivers per minute. Now, the registered number of revolutions was 360, corresponding to 88.8 miles per hour—a slip of 19 per cent.

"Surprised at these results, the writer repeated the same observations on a certain number of locomotives of different types, comparing the speed with the revolutions of the drivers. It was generally found that the slip was slight on an up grade, but very apparent on a down grade, ranging from 13 to 25 per cent. It increased rapidly with the speed."

This evidence appears pretty conclusive, especially as other articles and paragraphs to the same effect have appeared from time to time, accompanied by various reasons why the centrifugal force of the counterweights, and what not, must have the effect of producing it.

540. As a result of these tests it was concluded that "common locomotives" were "actually unsuited for speeds of 60 to 75 miles per hour," because the slippage was as much as 20 per cent. In a specific instance (the Uetliberg road) referred to in the paper it was said that on grades of 7 per cent (370 ft. per mile;-less by 1 per cent than is now successfully operated in Colorado, and less by 3 per cent than was successfully operated on temporary lines by the late Benj. H. Latrobe) "the slip of the driving-wheels was found so considerable that the gear system was found more economical," in spite of the slow speed.

541. On the other hand, tests of various American passenger locomotives at speeds at from 75 miles per hour down, made by Prof. Chas. A. Smith, Mr. Albert F. Hill, and Messrs. Henry Abbey and Oscar H. Baldwin (see *Engineering*, Aug., 1885), to mention no others, have uniformly indicated that no such phenomenon occurs with American locomotives under any circumstances.

There is an undoubted possibility, so far as this evidence alone is concerned, that the phenomenon might not occur with American locomotives, and might occur with differently constructed foreign locomotives; but in addition to the grave reasons for questioning the physical possibility of the assumed phenom-

enon, as being contrary to what is known in other ways of the laws of friction, it is not difficult to see how the alleged slipping may have occurred and yet have been in no respect "imperceptible" slip, nor different in any way from ordinary slipping, which is perceptible enough.

542. When a locomotive is only moving itself, especially if running down a grade, and so having little work to do, and when all possible power is put on to run, in literal truth "as fast as the wheels can turn," whether the wheels are slipping or not will make no very conspicuous difference in their speed of revolution; while, on the other hand, the work required of the locomotive, simply to keep up speed, will be so small that, when the wheels once begin to slip, the loss of power will not be so great as to prevent the acquirement and maintenance of very high speed, although they will continue to slip indefinitely, nevertheless. On the other hand, with a train of even one car behind the engine no high speed could probably be maintained under such conditions, for the minimum power to maintain the speed would then be so great that the speed would be immediately checked, and make it clear to the senses that the wheels were slipping. Whenever the locomotive was running up any considerable grade it would be still less possible; and the cautious statement quoted above, that it was "generally found" that "the slip was slight" on an up grade, probably means that, as a matter of fact, no absolute evidence of any slip was detected, or the figures for it would have been given.

543. To make the true explanation of the phenomenon clearer: Suppose, when the wheels of a freight engine were slipping, while it was standing still, that the engine were simply uncoupled—instead of shutting off steam in the usual fashion. If the grades were not too unfavorable the engine would probably start ahead, the wheels still slipping; and if all the steam were put on, on a favorable down grade, a velocity of "74½ miles per hour" might possibly be obtained, with an "imperceptible slip" of 20 per cent. These, or something like these, are probably the conditions, and the only conditions, under which the phenomenon has ever been observed, and they correspond to nothing in the worst extremes of practical operation. The only thing really proved by such "tests" is that even if the wheels are slipping in ordinary fashion they will kick hard enough against the rails to make an unloaded engine move down a grade at a very lively pace; which illustrates how easy it is to draw wrong conclusions from observed facts.

544. The effect of the CENTRIFUGAL FORCE OF THE COUNTERWEIGHTS of the locomotive to modify the pressure of the wheels on the rail is considerable, and especially on bridges very important, but as respects its effect on the adhesion it is less important, if indeed it can be said to be of any importance.

The counterweights are weights added to balance the piston and other reciprocating parts, and thus prevent serious disturbance of the

motion of the engine. They are either cast-iron weights between the spokes of the drivers or lead poured into hollows in the wheel-centre, and have the effect to make the wheel lop-sided. When the counterweights are in the position *a*, Fig. 108, their centrifugal force will be so much added to the weight carried by the wheel, and increase its pressure on the rail by so much. When they are in the position *a'*, at the top of the wheel, the centrifugal force will decrease the pressure on the rail. When they are in the position *b* and *b'* the centrifugal force will have no vertical effect.

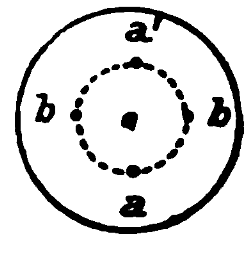
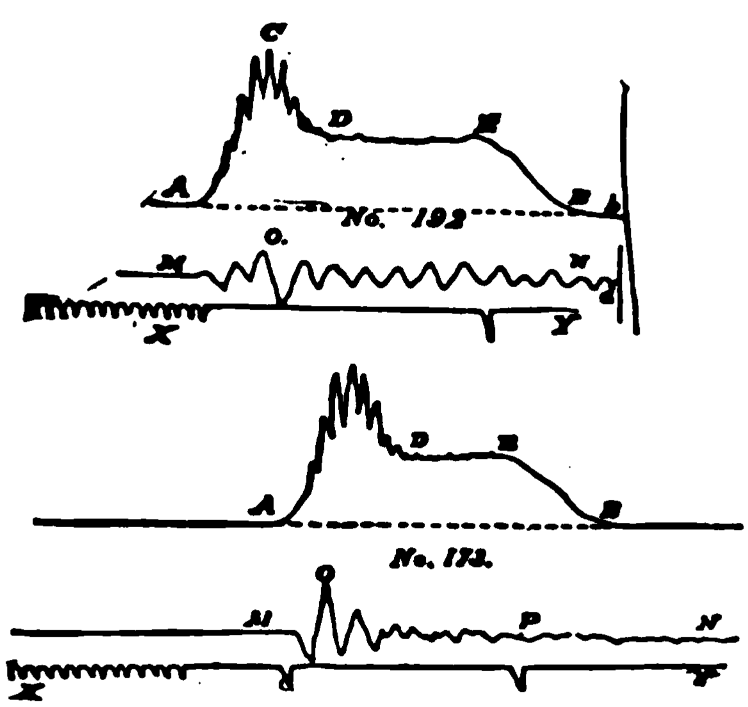


FIG. 108.

As respects freight engines, especially when the engine is working hard enough to be in any danger of slipping the wheels, the speed is ordinarily so slow that the centrifugal force of the counterweights is all but imperceptible. As respects passenger engines, the counterweights can at worst exert no appreciably injurious effect upon the adhesion, for the reason that the possible BOILER tractive power decreases with speed very much faster than it can be diminished by any possible effect of the counterweights.

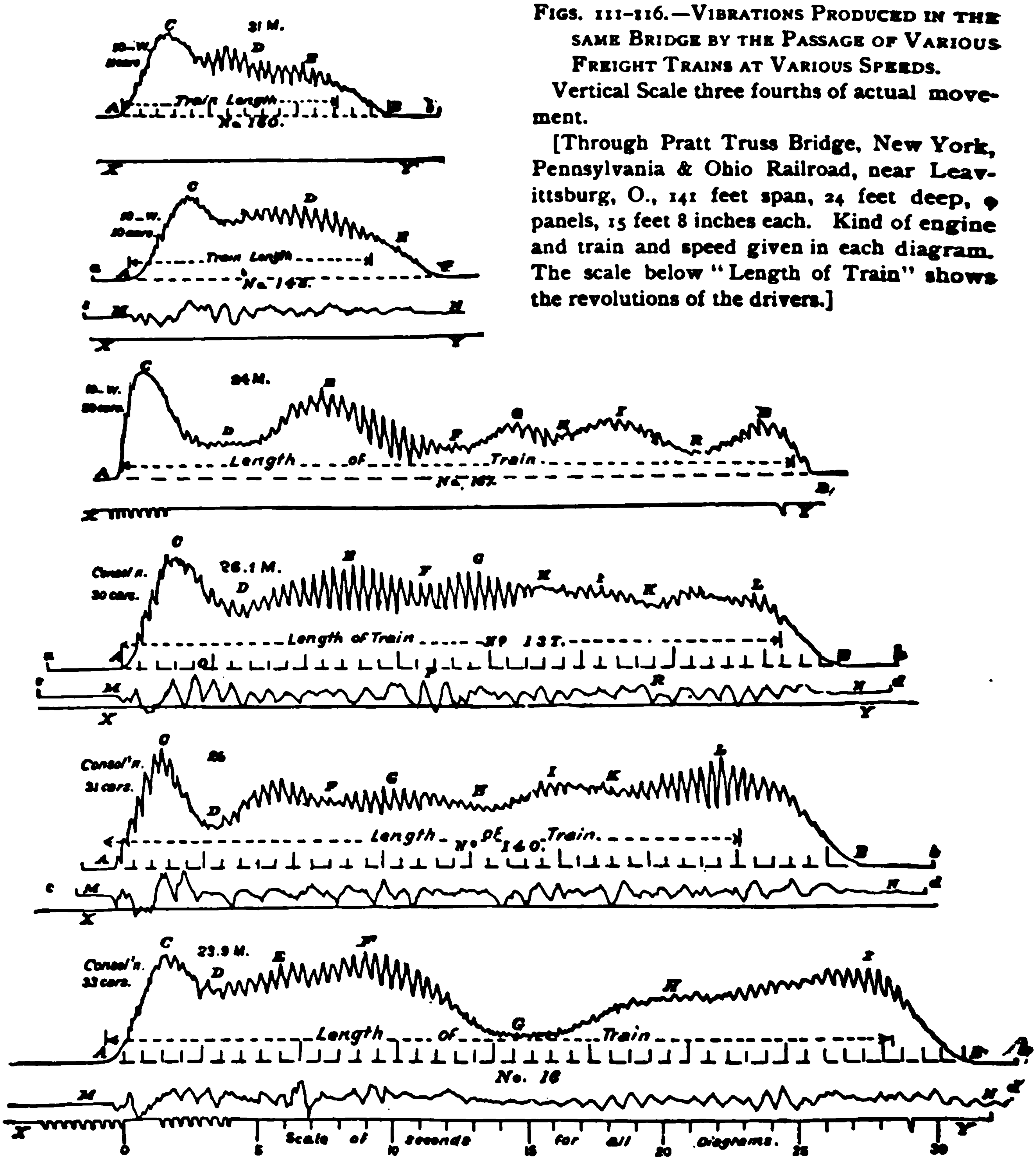
545. But while this phenomenon has no measurable effect upon the adhesion, and is not likely to have a very serious effect upon the track, it may and does have such effect on bridges. The sharp variation which takes place in the load on the rails has no effect on the riding of the engine, since it does not act through the springs. But it does give to the rail what has been not inaptly termed a "hammer-blow;" and its effect on bridges (especially on over-light bridges; see Chap. XXIII.) is visible in the striking diagrams reproduced in Figs. 109–116, which show how very greatly the oscillations of bridges are increased when the period of revolution of the drivers happens to coincide with the period of oscillation of the bridge.

Figs. 109–116 are from observations on the vibration of bridges by Prof. S. W. Robinson. They show the vertical and lateral vibrations of the panel point nearest the middle of its lower chord during the entire passage of the train.



FIGS. 109, 110.—EFFECT OF PASSAGE OF FAST PASSENGER TRAINS (40.8 AND 42.1 MILES PER HOUR) OVER THROUGH PRATT TRUSS, 148 FT. SPAN.

The upper line, *AB*, shows the vertical movements, and the lower one, *MN*, the lateral movements. The lowest one, *XY*, is a line of reference. As a train



FIGS. 111-116.—VIBRATIONS PRODUCED IN THE SAME BRIDGE BY THE PASSAGE OF VARIOUS FREIGHT TRAINS AT VARIOUS SPEEDS.

Vertical Scale three fourths of actual movement.

[Through Pratt Truss Bridge, New York, Pennsylvania & Ohio Railroad, near Leavittsburg, O., 141 feet span, 24 feet deep, 9 panels, 15 feet 8 inches each. Kind of engine and train and speed given in each diagram. The scale below "Length of Train" shows the revolutions of the drivers.]

approached the indicator was started, making the straight lines to the left of *A*, *M* and, *X*. As the train struck the bridge lateral motion of the pencils began, and it will be seen that in all cases the deflection was greatest within a second or two after the locomotive had entered upon the bridge, or about when the whole of the engine and tender was fairly on the bridge, and long before it had reached even the middle point of the bridge.

The hollow in the diagrams, which immediately follows, showing a reaction from

this extreme depression, indicates clearly that the latter is a dynamic effect, the sudden depression caused by the entrance of the load setting the bridge in motion downward so quickly that its momentum carries it down far below what even much greater static strains are able to maintain. It is probable that bridges of longer span and greater weight would show this effect much less markedly.

The length of train and also a scale (on the right line between *A* and *B*) on which the revolutions of the drivers are indicated has been added to the originals.

It will be seen that in every instance the vibrations of greatest magnitude are almost exactly synchronous with the drivers' revolutions, but as the vibrations decreased they become less so, and when the vibrations become a mere wavy line there is no observable connection whatever with the drivers' revolutions.

The difference in the effect of passenger and freight trains, or of different construction and speed, as shown by comparing Figs. 115–16 with Figs. 109–10, is very noticeable and curious.

THE LOCOMOTIVE BOILER.

546. To burn more than 80 lbs. of coal per square foot of grate per hour is sure to decrease the efficiency of combustion, although as much as 100 lbs. may be burned under favorable conditions, with fair economy. When combustion is pushed beyond this, as it not unfrequently is, sometimes even so far as to apparently double it, it is all but certain that a large proportion of the additional coal supply will be ejected at once from the smoke-stack, unconsumed. As much as 20 per cent of the entire coal put into the fire-box has been actually caught in the smoke-box, and it is quite certain that when more than 130 to 150 lbs. per square foot are "burned" nearly the whole of the excess of supply is thus ejected (see Table 146). Fig. 117, with its accompanying note, gives a rather exaggerated instance of what is continually taking place. The minimum waste of coal in this way is probably 5 per cent.

FIG. 117.—LUMP OF UNCONSUMED ANTHRACITE COAL, NATURAL SIZE, EJECTED FROM THE SMOKE-STACK OF AN EXPRESS LOCOMOTIVE WITH SUCH FORCE AS TO FALL IN THROUGH THE OPEN WINDOW IN THE SECOND CAR IN THE REAR.

(This lump was picked up by Mr. Geo W. Parsons, who handed it to the writer, still hot. The most salient angles only had been ignited, and they but slightly. No larger lump, perhaps, could be found with such a record, but innumerable smaller ones. The lump was nearly a cube. If partially ignited its specific gravity would have been much reduced, and it would have been more easily carried out by the blast, but probably broken up in the process.)

547. The ordinary evaporation of water per pound of coal burned is hardly more than 6 lbs. in this country, and sometimes only 5 lbs., or even less, although it rises to 8 or 9 lbs. in some cases,

and very frequently if not usually does so abroad, where the evaporation is more economical than is common here, owing in great degree to the combustion being less pushed by the hauling of heavy loads, and in part, probably, to more skilful firing. Theoretically, a fair ordinary coal (of 14,000 heat-units—not by any means the best—see Table 140) ought to evaporate something over 12 lbs. from water at 60° Fahr. to steam at 120 lbs. pressure.

Table 140.

Heat-units in Various Fuels.

	Heat-units.		Evap. Power (lbs. water) from and at 212°.	
Pure carbon	....	14,500	....	15.02
Pennsylvania anthracite	....	14,500	....	15.02
Pittsburg bituminous	....	14,200	....	14.69
Illinois coal (pure quality)	8,000 / 10,000	9,000	....	9.20
English coal (average)	14,858 / 13,860	14,320	14.34 / 15.52	14.82
English coke (average)	14,150 / 12,300	13,550	14.64 / 12.72	14.02 lbs.
Crude petroleum	....	20,240	....	20.33 "
Lignite	9,834 / 14,449	11,678	10.18 / 14.96	12.10 "
Asphalt	....	16,655	....	17.24 "
Dry wood (all kinds)	....	7,792	....	8.07 "

The heat required for evaporation "from and at 212° (i.e., the conversion of water at 212° into steam at 212° or atmospheric pressure) being 1.00, the heat required to turn water at normal feeding temperatures into steam of usual working pressures is as follows:

Feed-water. ° Fahr.	Steam Pressure above Atmosphere—Lbs.							
	20	40	60	80	100	120	140	160
40°	1.193	1.203	1.209	1.214	1.219	1.223	1.226	1.229
60°	1.172	1.182	1.188	1.193	1.198	1.202	1.205	1.208
80°	1.151	1.161	1.167	1.172	1.177	1.181	1.184	1.187
100°	1.131	1.141	1.147	1.152	1.157	1.161	1.164	1.167

(Abstracted from a large table in "Steam-Making," by the late Prof. Charles A. Smith.)

The lowest rates of evaporation occur with the highest rates of combustion, and *vice versa*; and ordinarily it is not possible to evaporate more than 600 lbs. of water per square foot of grate per hour (say 80 lbs. coal × 7½ lbs. evaporation ratio, or 100 lbs. × 6) for any length of time.

More may be done, but it cannot be relied on, and 500 lbs. of water per square foot of grate would come nearer to a moderate working maximum.

548. The ordinary load on drivers per square foot of grate ranges from 2500 to 4000 for ordinary types, as shown in Tables 127–130; 3000 lbs. being rather low for passenger engines of the American type and for Consolidation engines, and 4000 rather low for Mogul and Ten-wheel engines. The larger proportion of grate surface in the Consolidation type may be considered as in part a concession to the difficulty in firing such engines.

549. The steam used in the every-day working of locomotives (including the entrained water carried along with the steam mechanically) to do 33,000 ft.-lbs. of net effective work * is somewhat under 30 lbs., never, probably, running very much higher than that, and rarely quite as low as to 25 lbs., even under the most favorable circumstances; that being the lowest fair assumption for steam used at slow speeds on long grades or at other specially favorable points, except that for very short distances considerably more than that may be shown, owing in part to drawing on the small reserve of power in the boiler (par. 553 and Table 144).

550. Then, as the production of steam is 600 lbs. per square foot of grate per hour, and the consumption per horse-power per hour is rarely better than 25 lbs. and often much worse, we have $\frac{600}{25} = 24$ horse-power as the maximum ordinary capacity of one square foot of grate area. Tables 146 and 147 will indicate that this is, on the whole, a rather favorable showing for what can be actually realized. But to determine the very highest maximum which can be claimed in the way of locomotive performance, we may appropriately refer to Mr. Wm. Stroudley's paper on the locomotive performance of the London, Brighton & South Coast Railway (Trans. Inst. C. E. 1885), where we find that an average of about 600 *indicated* horse-power was maintained for 6 or 8 miles in succession by an engine with 17.04 square feet grate area, with an average horse-power for the whole run of 50 miles of 528.5, corresponding to

$$\text{Indicated H. P. per sq. ft. grate} \begin{cases} \text{maximum } \dfrac{600}{17} = 35.3 \text{ H. P.} \\ \text{average } \dfrac{528.5}{17} = 31.1 \quad \text{"} \end{cases}$$

Net effective " " " (10 per cent less), say, 32 and 28 H. P.

In round figures, 30 effective horse-powers per square foot may be said to be the ultimate limit.

551. The horse-power which, if it could be produced, might be trans-

* For one hour.

mitted through the drivers for propelling the train is very much greater than this except at the slower speeds, so that at the slower speeds only is it possible to utilize the full adhesion, as may be determined thus:

	Per Square Foot of Grate Area.
Usual load on drivers, as per Table 141,	3,000 to 4,000 lbs.
Equivalent tractive power for $\frac{1}{4}$ adhesion,	750 to 1,000 lbs.

TABLE 141.

LOAD ON DRIVERS PER SQUARE FOOT OF GRATE AREA FOR THE VARIOUS LOCOMOTIVES GIVEN IN TABLES 127–130.

TABLE 127.—AMERICAN ENGINES.

Date.	Road or Maker, and Cylinders.	Lbs. per sq. ft.
1873 ..	Mason, 17 × 24	2,440
1884....	No. Pacific, 17 × 24...... ..	3,390
1884 ...	Brooks, 17 × 24.............	2,920
1884 ..	C., B. & Q.. 17 × 24...... ...	3,050
1884....	" " 18 × 24.........	3,070
1884....	Mason, 18 × 24.......... ..	3,590
1834 ...	West Shore { A	1,880*
	West Shore { B	3,670

TABLE 128.—TEN-WHEEL ENGINES.

Date.	Road or Maker, and Cylinders.	Lbs. per sq. ft.
1873 ...	Baldwin, 18 × 26...........	4,020
1883....	Brooks, 19 × 24.............	3,230

TABLE 128.—MOGUL ENGINES.

Date.	Road or Maker, and Cylinders.	Lbs. per sq. ft.
1873...	Baldwin, 18 × 24.......	4,120
1883...	Brooks, 18 × 24.....	4,270
1884...	Baldwin (N.S.Wales), 18 × 26	4,650

TABLE 129.—CONSOLIDATION ENGINES. 20 × 24 cylinders.

Date.	Road or Maker, and Cylinders.	Lbs. per sq. ft.
1875-6.	Penna. "Class I".........	3,450
1886...	" "Class R"........	3,210
1883...	West Shore	3,830

TABLE 130.—MASTODON ENGINES.

Date.	Road or Maker, and Cylinders.	Lbs. per sq. ft.
1882...	Central Pac., 19 × 30.......	4,120
1882...	Lehigh V., 20 × 26.........	2,570*

* These engines have specially large grates to permit of slow combustion.

Then the horse-power per hour per square foot of grate area which will or might be transmitted through the drivers, if their utmost adhesion be utilized, will be—

$$\text{Max. H. P.} = \left.\begin{matrix}\text{load on drivers}\\ \times \text{ coeff. adhesion}\end{matrix}\right\} \frac{5280}{33{,}000 \times 60} \times \text{speed in miles per hour.}$$

By this formula Table 142 was computed, which indicates at once a truth of the first importance—that it is absolutely impossible to produce enough power in the boiler to utilize more than a small fraction of the available tractive power at any of the higher speeds, and it is only as we fall below 15 miles per hour that it becomes possible for even freight engines to do so.

TABLE 142.

HORSE-POWER OF NET EFFECTIVE WORK REQUIRED TO BE CONTINUOUSLY GENERATED PER SQUARE FOOT OF GRATE AREA TO FULLY UTILIZE THE ENTIRE TRACTIVE FORCE OF VARIOUS ENGINES AT VARIOUS VELOCITIES.

Adhesion assumed, $\frac{1}{4}$. Reduce by one-fifth part to correspond to $\frac{1}{5}$ adhesion.

Pounds on Drivers per Square Foot of Grate Area.		Horse-power to be supplied per Square Foot, at Velocities in Miles per Hour.					
		10	15	20	30	40	50
2,000	Minimum	13.33	20.0	26.67	40.0	53.33	66.67
2,500	for	16.67	25.0	33.33	50.0	66.67	83.33
3,000	American engines.	20.00	30.0	40.00	60.0	80.00	100.00
3,500		23.33	35.0	46.67	70.0	93.33	116.67
4,000	Freight types.	26.67	40.0	53.33	80.0	106.67	133.33
4,500		30.00	45.0	60.00	90.0	120.00	150.00

The black line marks the limit at which it ceases to be physically possible, under the most favorable circumstances, for the boiler to produce sufficient steam to utilize the full adhesion, allowing 30 horse-power per hour per square foot of grate (an ordinary maximum being 24 horse-power) and for $\frac{1}{4}$ adhesion. To add a similar line corresponding to $\frac{1}{5}$ adhesion, draw the line at 37.5 horse-power instead of 30 horse-power, as indicated by dotted line, making little change.

552. There is, however, one more resource for eking out deficiency of boiler power—to draw upon the reserve in the boiler itself, either by pumping in no feed-water for the time being, or by allowing the pressure to fall somewhat while the excessive demand continues, or both.

Neither of these resources amounts to much, although both assist very slightly. As respects variations of pressure; as the pressure of steam rises or falls, the *sensible* temperature of the steam rises or falls very rapidly, but the total heat per pound of steam is little affected—so little that the total heat was at one time supposed to be constant for all pressures. This is shown in Table 143, on the following page:

553. A very small excess of demand for steam, therefore, will cause the pressure to fall very rapidly, and as there are only 20 to 30 lbs. of live steam stored in the boiler at any one time, what is gained by letting

TABLE 143.

WEIGHT OF AND HEAT IN STEAM AT VARIOUS PRESSURES.

Pressure, Lbs. per sq. in. above atmosphere.	HEAT-UNITS.* Sensible.	HEAT-UNITS.* Total.	Weight per cu. ft. Lbs.
0	212.0	1178.1	.038
20	259.3	1192.5	.086
50	281.0	1199.1	.120
100	338.0	1216.5	.263
120	350.1	1220.2	.308
140	361.0	1223.5	.350
160	370.8	1226.4	.393

Full tables giving these properties of steam for each point of pressure will be found in D. K. Clark's "Manual for Mechanical Engineers," and in many other treatises. The pressures given above the atmosphere should be 0.3 lb. greater, and the total pressure measured from a vacuum 15 lbs. greater. These figures rest purely on experiment, from which accurate formulæ have been deduced.

TABLE 144.

AVAILABLE ENERGY IN HEATED WATER AND STEAM OF LOCOMOTIVE BOILERS,

Between normal temperature of steam and 212° Fahr., or that available in case of explosion. For practical working the available stored energy is very much less than this. See top of next page.

[Abstracted from a paper on "Boiler Explosions," by Prof. R. H. Thurston, Trans. Am. Soc. M. E., Vol VI., Paper CLXII.]

AREA OF—		WEIGHT OF—			STORED ENERGY AVAILABLE—			
Grate.	Heat'g surface.	Boiler.	Water.	Steam.	Water.	Steam.	Total.	
sq. ft.	sq. ft.	lbs.	lbs.	lbs.	ft.-lbs. 1 = 1000	ft.-lbs. 1 = 1000	ft.-lbs. 1 = 1000	mile-lbs 1 = 1
15	875	14,020	6,330	19.02	64,253	2,385	66.638	12,621
20	1,200	20,565	6,450	25.65	64,452	3,226	67,678	12,818
23	1,070	19,400	5,260	21.67	52,561	2,717	55,278	10,469
30	1,350	25,000	6,920	31.19	69,149	3,910	73,059	13,837

* The heat-unit must be carefully distinguished from a mere degree of temperature, from which it differs much as a *foot-pound* differs from a pound or a foot, or as an area differs from a distance. The little diagrams on the next page (Figs. 118, 119, and 120) will make this clearer. A heat-unit is a *quantity* of heat. What is called temperature is merely an *altitude* of heat. A high altitude of temperature is consistent with a very small quantity, if the body be small, or even if the body be large and its capacity for absorbing or holding heat small. Different materials differ greatly in this respect.

Assumed steam pressure, 125 lbs.

This table gives the entire energy in the steam and water between 212° and 353°, or the amount of work which would be done if the pressure were allowed to fall to zero and there were no back pressure or other losses in the cylinder. It will be seen to be about equal to the ordinary working tractive power of a powerful engine for about one mile. Perhaps one half of this stored energy is a practically available resource in operating emergencies.

pressure drop from 140 lbs. to 50 lbs. is simply this, say, for the second engine given in the preceding Table 144:

In Steam Space: Only 8.8 instead of 25.6 lbs. of steam are required to fill the steam space, releasing some 17 lbs. of steam.

In Water Space: The fall of sensible temperature from 361° to 281° releases 80 heat-units per pound of water, and 80 × $\frac{1}{8}$ (specific heat of iron) heat-units per pound of boiler, being sufficient to convert into steam a weight of water equal to about $\frac{1}{13}$ of the total weight of boiler and contained water, or for the given engine 728 lbs. of steam.

This makes a total gain of only 745 lbs. of steam, or 37½ lbs. per square foot of grate, which is about what a square foot of grate should evaporate in 3¾ minutes, at the rate of 600 lbs. per hour.

554. As respects letting the supply of water fall off, here also the gain is comparatively slight, because the heat used to raise the temperature of the water, say, from 60° to the boiling-point at 120 lbs. pressure, 350°, is only 290 heat-units per pound of water, or one third ($\frac{290}{868}$) as much as is needed to change the water into steam after it has reached that limit. Therefore, even if we allow as much as 10 per cent of the whole water in the boiler to evaporate without replacing it, which will lower it about 3 in., we only save heat enough to evaporate $\frac{1}{30}$ of the whole water in the boiler, or 215 lbs.,

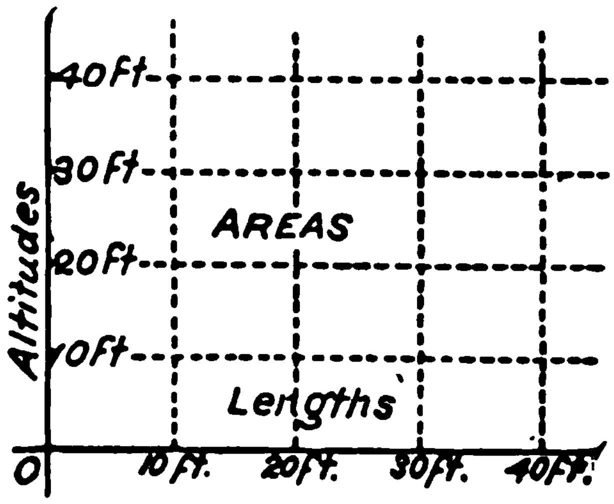


FIG. 118.—RELATION OF AREAS TO ALTITUDES AND LENGTHS.

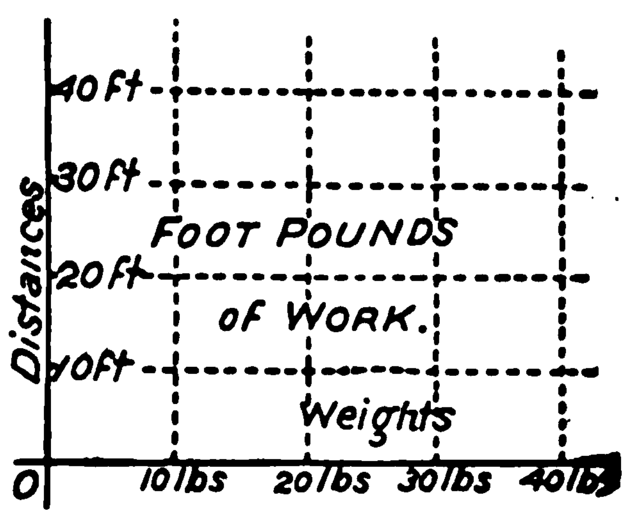


FIG. 119.—RELATION OF FOOT-POUNDS OF WORK TO DISTANCES AND WEIGHTS.

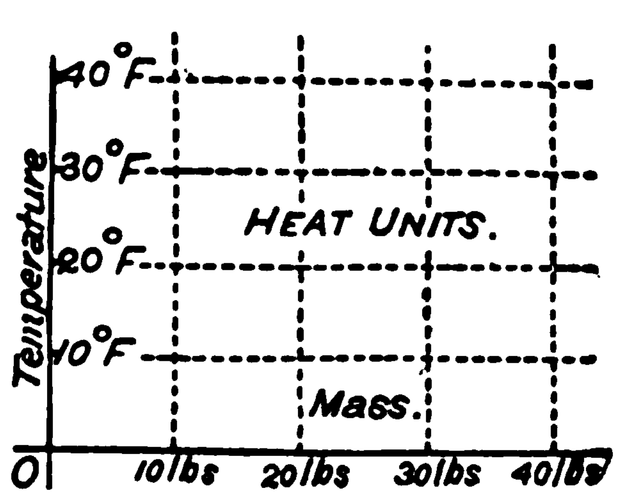


FIG. 120.—RELATION OF HEAT-UNITS TO TEMPERATURE AND MASS.

being somewhat over 10 lbs. per square foot of grate, or about what is evaporated in one minute.

555. Nevertheless it helps; but that the help is small, is clear in another way from Table 144, which gives the total available energy in the boiler and contents if the boiler pressure were allowed to fall to zero, and the steam thus produced used without loss (other than the heat in the steam at 212°) in the cylinders.

It will be seen from Table 144 that an engine which is working fairly hard (as hard as it can continue to work indefinitely), and evaporating 600 lbs. per square foot of grate, will evaporate a whole boilerful of water in from 20 to 40 minutes. This, again, shows that the available reserve

TABLE 145.

ESTIMATED APPROXIMATE DISTRIBUTION OF THE LOSS OF HEAT IN AMERICAN LOCOMOTIVE BOILERS TO ITS VARIOUS CONTRIBUTING CAUSES.

	MAXIMUM.		MINIMUM.	
	Lbs.	Per cent.	Lbs.	Per cent.
Theoretical evaporation of fairly good (14,000 H. U.) coal	12.07	100.	12.07	100.
Actually evaporated in fair average practice, with such coal	9.06	75.	6.04	50.
Leaving as wastage to be accounted for, which may be divided between the various sources of loss, as follows:	3.01	25.	6.04	50.
1. Heat carried off in the gases of combustion (extremes of smoke-box temperature taken at 392° and 724°)	1.21	10.	2.42	20.
2. Lost in the ash	....	0.+	....	0.+
3. Getting up steam and banking fires (about 10 per cent, but not included above, and so neglected.)	....	....	....	....
4. Unconsumed coal ejected by the blast	.36	3.	1.21	10.
5. Imperfect combustion	....	....	.60	5.
6. External radiation	1.44	12.	1.81	15.
7. Entrained water (a real loss but apparent gain)	−0.12	−1.	−0.61	−5.
8. Lost through safety-valve	0.12	1.	0.61	5.
Total loss as above estimated	3.01	25.	6.04	50.

These extremes are rarely reached in the same engine, but the maximum is only reached under favorable and the minimum under unfavorable conditions for economical combustion.

In marine practice, nearly all the above sources of loss except the first are avoided. An efficiency of from 80 to 90 per cent of the theoretical evaporation is therefore no longer exceptional.

in the boiler is a pretty small affair, and the normal generation of steam we have seen (Table 142) to be quite unequal to utilizing the full tractive power at any high speed.

556. The boiler is not an uneconomical generator of power. In the best types, from 75 to 90 per cent of the potential energy which goes into it in the form of fuel leaves it in the form of steam. Nor is the locomotive boiler, in spite of its great efficiency in proportion to weight, inferior to other types in economy, the very best of stationary and marine boilers alone excepted. Without going into details, for which space cannot be taken, Table 145 gives the substance of the facts in relation to its ordinary working when not burning over 80 to 100 lbs. of coal per hour. When combustion is pushed harder, the loss from unconsumed coal ejected by the blast is much heavier.

THE CYLINDER POWER.

557. Since we have seen that the locomotive boiler is quite unequal to supplying steam enough to utilize the full adhesion at high speeds, it results in no serious loss, and need occasion no surprise, that the cylinder, which is a mere transmitting agency, is in actual practice and as actually constructed unequal to transmitting such an amount of power, even if it could be generated. As the speed rises above the lower working speeds for which the locomotive was designed there is a very great reduction of cylinder efficiency as measured by the average pressure in the cylinders, cut-off, opening of throttle, and boiler pressure being the same.

558. The steam-engine, even in its most perfect forms, attempts only to convert into work the *expansive* energy of steam, which is a very small part of its total energy. All that great proportion of the heat energy in the steam which has been required for the purpose of changing it from water into steam is wholly thrown away, even in a theoretically perfect steam-engine. It is hardly to be conceived of that science will not eventually discover some radically different device for converting heat into work which will be many times more effective, but at present we do not seem to be even tending toward it.

559. All ordinary forms of steam-engines are in substance similar to the engine of the locomotive, which in its essential outlines is simplicity itself, consisting only of a piston vibrating back and forth within a cylinder to which steam is admitted and cut off at each end alternately by some form of automatically-acting valve—in the locomotive, the slide-valve. The steam is admitted for a certain fraction of the stroke (one

quarter to three quarters in the ordinary practice of the locomotive), called the *period of admission;* then cut off, permitting what steam is shut up in the cylinder to expand and do further work during what is called the *period of expansion;* and then *released* or permitted to escape at or before the end of the stroke, so that there may be as little as possible *back pressure* to resist the return stroke.

While this division of the work done in the cylinder into the period of "admission" and of "expansion" is convenient, yet during each period alike it is the expansive energy of the steam, and that alone, which does what work is done.

560. On the proper design of the valve-gear by which the slide-valve is moved, and so the admission, cut off and release of the steam controlled, hangs nearly the whole question of good or bad working of the cylinders, and its theory is a study in itself, into which we need not enter; contenting ourselves with determining what are the theoretical limits of efficiency, what are the results actually obtained in good practice, and how these results ought to be and are affected by varying conditions.

561. The form of valve-gear known as the link-motion is in all but universal use on American engines, and is used on a large majority of all foreign engines. It was invented almost contemporaneously with the locomotive itself, and a large part of the credit for it is due to the same man, George Stephenson; so that it is not unjustly known by his name, although it is, properly speaking, the invention of Howe, a foreman in his shops. It has not been essentially modified or improved upon since its invention, except as advancing experience has given better knowledge of the precise proportions which it should have, and it is with justice regarded as one of the most notable inspirations in the history of mechanism, fulfilling as it does very simply yet remarkably well all the complex requirements which a locomotive valve-gear should have.

562. Nevertheless there are certain desirable ends which it does not fulfil, and in recent years a number of valve-gears have been devised, some of them of a highly ingenious character, which are claimed, and probably with truth, to possess certain practical advantages over the link-motion, and which have met wide acceptance abroad. It is possible, although as yet hardly probable, that some of these may eventually supplant the link-motion, but none of them have yet been shown to give such radically different results from the link-motion that any of the conclusions we shall reach will be affected thereby, except in degree.

563. Assume such a cylinder as that described in par. 559 to have a connection opened with the boiler, at the beginning of the stroke, which continues open until the end of the stroke. Let the connection with boiler be then closed, and a connection with the outside air opened, so

as to permit the inclosed steam to escape, while at the same time steam is admitted to the other end of the cylinder and the operation is repeated.

564. In this we have a steam-engine of the simplest type, which was also the earliest type, and an indicator-diagram of such an engine, if it worked perfectly (which it would not be likely to do at very high speed), would resemble Fig. 121. The boiler, being constantly generating steam, may be considered as, for the time being, a reservoir of infinite volume, and the expansion of the steam to fill the cylinder will not reduce its pressure. Consequently, the cylinder pressure throughout the stroke will be equal to the boiler pressure, and the diagram will be a rectangle, in which the foot-pounds of work done will be represented by *stroke in ft.* × *area of piston in sq. ins.* × *boiler pressure in lbs. per sq. in.* The efficiency of even so crude an engine as this is considerably over three fourths of what is actually realized in fair average practice, and fully as much as is realized under unfavorable conditions, and may be determined thus :

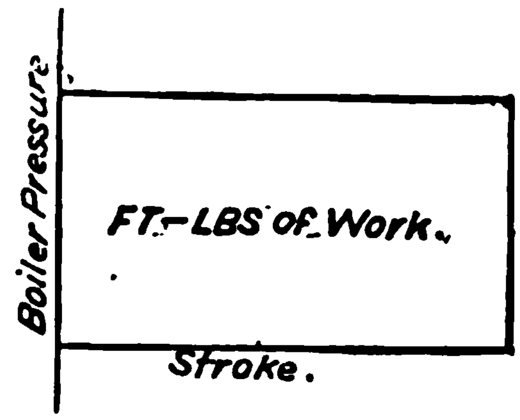


FIG. 121.

565. A 17 × 24 in. cylinder has a capacity of 3.1525 cu. ft., and will hold almost precisely *one pound* of live steam at a pressure of 126 lbs. per sq. in. above the atmosphere—an ordinary working pressure. The work done by this steam, in foot-pounds, if there be no loss by condensation or other disturbing cause, will be

$$\frac{\pi 17^2}{4} \times 126 \text{ lbs.} \times 2 \text{ ft.} = 57,200 \text{ ft.-lbs.}$$

Dividing this amount of work by the mechanical equivalent of heat, we obtain as the useful work which ought to be realized if there were no losses by back pressure of steam, condensation, or otherwise,

$$\frac{57,200}{772} = 74.09 \text{ H. U.}$$

In addition to this useful work the steam has, in a non-condensing engine, done this work against the pressure of the atmosphere on the opposite side of the piston, amounting to nearly 15 lbs. per sq. in., or about 11.2 per cent of the useful pressure. Computed to include work done against this pressure, most of which is avoided in marine and other condensing engines, the total work done is equivalent to $74.09 \times 1.112 = 82.91$ H. U.

Now the total heat in this quantity of steam is (Table 143) 1221 H. U., so that all that is utilized is :

Cutting off at Full Stroke.

In a perfect non-condensing engine,

$$\frac{74.09}{1221} = 6.07 \text{ per cent.}$$

In a perfect condensing engine,

$$\frac{82.9}{1221} = 6.79 \text{ per cent.}$$

Practically even this result is 7 or 8 per cent too great, owing to the steam wasted to fill the passages between the valve and the piston, which does no work whatever unless the steam is expanded after being cut off.

566. There being $33{,}000 \times 60 = 1{,}980{,}000$ ft. lbs. in a horse-power per hour, we shall have to use, in order to develop a horse-power per hour with an engine worked in this way,

$$\frac{1{,}980{,}000}{57{,}200} = 34.62 \text{ lbs. of steam.}$$

And if we had a boiler able to utilize the full evaporative efficiency of fairly good coal, instead of only one half to three fourths of it, we should require $\frac{34.62}{12.07} = 2.87$ lbs. of coal to obtain one horse-power per hour.

567. Only under the most favorable possible circumstances for obtaining the last degree of efficiency out of the locomotive is it possible to obtain a horse-power per hour with 2.87 lbs. of coal, or with less than 25 lbs. of steam. Ordinarily in fact, even on long up grades which afford the most favorable localities for the economical working of the locomotive, something like 30 lbs. per horse-power is used (see Table 146). With ordinary evaporation of 6 to 8 lbs. of water per pound of coal from 4 to 6 lbs. of coal per horse-power per hour are required, and this is about what is ordinarily obtained from locomotives, the very finest marine engines running down to 1.3 to 1.5 lbs.

568. Many engines in times past have been, and in fact still are, run at nearly full stroke, as notably high-pressure engines on Mississippi River steamboats. In the locomotive this is occasionally done, but usually the steam is permitted to expand through about half the stroke. The theoretical gain from doing this is large, but the practical gain small—so small that nearly all that is gained by it is to neutralize the various practical obstacles to realizing the full theoretical work of steam at full stroke.

569. A theoretically perfect condensing steam-engine and boiler requires only ½ lb. per H. P. per hour of coal, and some 8 lbs. of water, at a boiler pressure of 120 lbs. per sq. in., utilizing a scant 26 per cent of the energy in the coal. A theoretically perfect non-condensing engine utilizes 16.9 per cent.

570. The very best ever claimed to have been realized with locomotives is in the paper by Mr. Wm. Stroudley before referred to (par. 550), where it is stated that in a trip of 50.4 miles at 43.3 miles per hour the average coal consumption

(exclusive of coal for getting up steam, which is about 3 lbs. per mile run) was 24.87 lbs. per mile, and the average horse-power developed 528.53 (see Fig. 123). This amounts to producing a horse-power with 2.04 lbs. of coal per hour —a result which has been approached elsewhere under the most favorable conditions, but when alleged as the result of an ordinary service run over undulating grades it is all but certain that its remarkably favorable result is largely due to serious errors in the record ; in great part probably originating in the shortness of the run, in which only some 1200 lbs. of coal is alleged to have been burned, or 1.2 cu. ft. per square foot of grate. The same allowance must be made for the alleged rate of evaporation, 11 6 to 12.6 lbs. per pound of coal, which, it is risking little to say, is from 10 to 20 per cent beyond the limits of physical possibility, in view of the fact that the gases in the smoke-box seem to have had a temperature of 600° Fahr.

571. A far better index of average practical results is that given in Tables

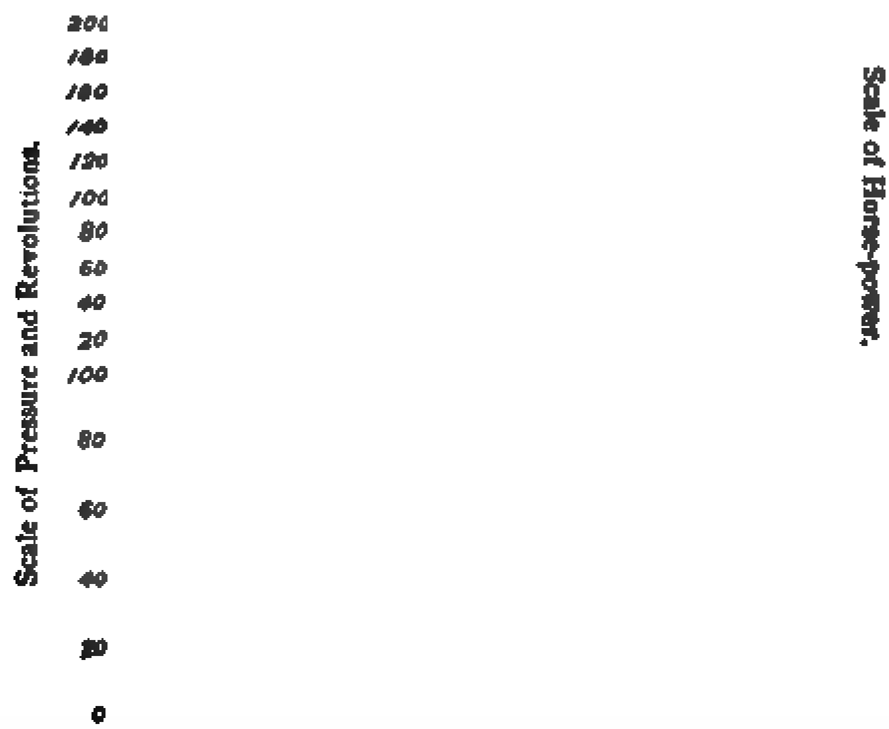


FIG. 123.

DIAGRAM SHOWING RESULTS OF A TEST OF A BALDWIN LOCOMOTIVE, BY JOHN W. HILL, M.E., DURING A RUN BETWEEN CINCINNATI AND HAMILTON, 24.7 MILES. (See Tables 146 and 147.)

[The abscissæ represent the intervals between indicator-diagrams, which were taken in as quick succession as possible (40 in 25 miles, or 1h. 26m.) and not miles.]

The mean effective pressure may be considered as the equivalent of the tractive power, which should theoretically fall immediately to zero on striking the down grade, if the velocity were to remain the same, but instead of this was maintained about the same for some distance, with the effect of greatly increasing the speed and horse-power.

146 and 147, where from 4½ to 5½ lbs. of coal per horse power per hour were required, rising, when combustion was so forced as to expel unconsumed coal

FIG. 123.—EXPERIMENTS ON THE LONDON, Express Passenger Engine, 18¼" × 26" cylinders, 6 ft. 6 in. drivers. Mean weight, 67.2 *long* tons, including tender; 31.14 tons on drivers. Weight of engine and 23 carriages, 335.7 tons. *Average of Whole Run:* Speed, 43.3 miles per hour; indicated horse-power, 528.53; tractive power, 4477 lbs.; maximum power, 11,590 lbs.; coal per mile, 24.87 lbs.

from the smoke-stack (as it often is in practice), to over 7 lbs. Fig. 122 shows the fluctuations of speed and tractive power during a part of this run in a somewhat similar manner to Fig. 123.

TABLE 146.

TESTS OF A BALDWIN 16 × 24 IN. AMERICAN ENGINE IN EXPRESS FREIGHT SERVICE.

[Deduced from Records of Tests by John W. Hill, M. E., Jour. Frank. Inst., April-May, 1879. For details of engine and train, see below.]

BOILER PERFORMANCE.	Cincinnati to Hamilton.	Hamilton to Twin Creek.	Twin Creek to Dayton.
	lbs.	lbs.	lbs.
Apparent evaporation, actual........	7.44	4.75	6.55
" " less 5 p. c. primage	7.07	4.51	6.22
Equivalent from and at 212°.........	8.36	5.34	7.30
Actual evap. (less primage) per sq. ft. of heating surface, per hour........	9.96	13.01	12.24
Coal burned per sq. ft of grate, per hour..............................	83.9	172.0	117.3
Evap'n from and at 212° per hour....	10,586	13,856	12,918
Estimating coal burned per sq. ft. of grate per hour with natural draft at 25 lbs., and one horse-power = 15 sq. ft., we have, for such an engine as above, for a	sq. ft.	sq. ft.	sq. ft.
Heating surface per H. P. of........	3.24	2.57	2.61
Ratio of effect of blast to natural draft, comparing by .... { coal burned....	3.36	4.34	4.04
Ratio of effect of blast to natural draft, comparing by .... { heating surface	3.32	4.33	4.08

BRIGHTON & SOUTH COAST RAILWAY.

Speed in miles per hour is indicated by the figures at the top of the diagram and by the heavy solid line. *Horse-power* is indicated by the dotted line made of points. *Tractive force* is indicated by the light-dotted line. The dotted lines along the base show where diagrams were taken, 49 in all. The three arrow-heads at the left indicate stops.

TABLE 146.—*Continued.*

Engine Performance.

Miles run	24.7	15.87	16.267
Speed, miles per hour	17.23	22.67	23.0
Mean boiler pressure	122.0 lbs.	124.0 lbs.	123.0 lbs.
" initial "	98.5 "	107. "	105.5 "
" cut-off	.53	.515	.52
" effective pressure	65.0 lbs.	64.2 lbs.	63.2 lbs.
Grade of expansion, incl. clearance	2.0	2.09	2.03
DISTRIBUTION OF POWER:	H. P.	H. P.	H. P.
Indicated H. P.	291.9	368.7	388.5
Power absorbed by engine only above all resistances	33.4	41.3	44.3
Gross load	258.5	327.4	344.2
Extra friction due to load (5 p. c. of gross load)	12.9	16.4	17.2
Power expended in moving train	245.6	311.0	327.0
Per cent of total power absorbed by engine	15.86	15.63	15.82
COST OF POWER:	lbs.	lbs.	lbs.
Steam per hour to engines	9,424.6	12,312	12,415
Steam accounted for by diagrams	8,017.2	9,883	10,324
Per cent of do	85.0	80.3	83.2
Steam per I. H. P. from boiler	32.3	33.4	32.0
" " " " diagrams	27.5	26.9	26.6
Coal per I. H. P., actual	4.24	7.03	5.36
" " " at 1 to 9 evap'n	3.59	3.71	3.55

These tests are perhaps as fairly representative of every-day American practice as any which exist. See details on following page and Table 147.

DETAILS OF ENGINE AND TRAIN FOR TABLES 146, 147.

Baldwin American engine, 16 × 24 in. cylinders, 61 in. drivers, 15.99 sq. ft. grate area, 898.7 total heating surface.

Weight on drivers, 44,840; trucks, 27,380; total, 72,220 lbs.

Weight of tender, empty, 23,480 lbs.; load, 24,000 lbs.

Train, 35 loaded box cars and caboose, weighing	782.94 tons.
Average of engine and tender	55.72 "
Total weight of train	838.66 tons.

Engine in ordinary working order, out of shop 22 months (55,471 miles), Pittsburg No. 2 coal. Date of tests, July 28, 1878.

Evaporation per sq. ft. of fire-box surface, assuming 60 per cent of the evaporation to have been from that surface, 93.53 lbs. per hour.

Friction of engine was determined by series of indicator-diagrams at each speed, averaging 15.8 per cent (including the allowance of 5 per cent for extra work due to load, which is probably too large), while the weight of the engine was only 6.65 per cent of the total. This work, however, includes atmospheric head resistance as well as rolling and internal friction.

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572. A more reasonable presentation of what may fairly be expected from locomotives under the most favorable working conditions for developing power economically is given in a paper on "The Consumption of Fuel in Locomotives," read before the Institution of Mechanical Engineers, by M. Georges Marié, engineer of the Paris & Lyons Railway, of France. In these tests a powerful locomotive ($21\frac{1}{4} \times 26$ in. cylinders, eight 4 ft. $1\frac{5}{8}$ in. drivers, carrying some 100,000 lbs.; exact figures not given) was loaded with a light train of 167.8 to 183.2 tons, and run up a long grade on the Mont Cenis line, rising 1709 ft. in $17\frac{1}{4}$ miles, or about a two per cent average grade (the maximum being 2.84 per cent), in one hour. The total tax on the adhesion on such a grade was only some 65 lbs. per ton maximum and 46 lbs. average, or a total average traction of some 8000 lbs. With so light a load it was possible to cut off at one-fifth stroke. The author's conclusions from the tests are that with a good locomotive and a good driver the consumption of fuel and water is as follows:

Consumption of fuel per effective horse-power per hour..	3.27 lbs.
Consumption of fuel per indicated horse-power per hour..	2.88 lbs.
Ratio of consumption of water to consumption of fuel....	8.88
Ratio of dry steam produced to fuel consumed..........	8.08

These satisfactory results are attributed to the following causes: "(1) The total heating surface of the boiler is very large compared to the grate surface,—96 to 1,—so that the boiler absorbs the heat of the gases very completely; (2) the cylinders of the locomotive are very large,—according to the late M. Marié's system,—so that the grade of expansion is high; (3) the locomotive was very well looked after, which is an important point in economy of fuel."

TABLE 147.

DETAILS AS TO THE RESISTANCES OF ENGINE AND TRAIN IN THE TESTS ABSTRACTED IN THE PRECEDING TABLE.

	C. to H.	H. to T. C.	T. C. to D.
In three runs of	24.7 miles.	15.87 miles.	16.27 miles.
At speeds in miles per hour of	17.23	22.67	23.0
		Average of—	
	40 cards.	20 cards.	21 cards.
		I. H. P.	
The average indicated H. P., as determined by the average of cards taken on both sides of the engine simultaneously at intervals of two minutes, was	291.9	368.7	388.5
		lbs.	
The entire weight of the train having been, engine, 55.72 + 782.94 = 838.66 tons, we may compute from the above data that the average tractive energy of the locomotive (including its own internal friction) was	6,346	6,097	6,334
		lbs. per ton	
Equal, average of entire train	7.57	7.27	7.55
		I. H. P., engine only	
Of the above H. P., however, it was determined by actual trial that the indicated H. P. necessary to move the engine alone at the given speeds was	33.4	41.3	44.3
And it was estimated that when the engine was working hard there was a further addition to its internal friction of 5 per cent loss on work done, =	12.9	16.4	17.2
Making total H. P. absorbed within engine	46.3	57.7	61.5
		lbs. per ton	
Deducting this from the work done, and deducting engine from weight of train, we find the average traction exerted *on the train* was	6.83	6.57	6.78
		Total lbs.	
Leaving as the power required to propel the engine itself, without load	727.	683.	722.
Add estimated addition to engine resistance when working hard (5 p. c.)	281.	272.	280.
Total continuous force in lbs. to move eng. itself.	1008.	955.	1002.
		lbs. per ton	
Or in lbs. per ton of engine and tender:			
Locomotive without load	13.04	12.26	12.96
Increase due to load	5.06	4.87	5.04
Total locomotive resistance	18.10	17.13	18.00
		Total lbs.	
Assuming the effective end-area of the engine for air resistance to be 100 sq. ft., and air resistance to be ⅙ lb. per sq. ft., at 10 miles per hour, we have for air head resistance only	148	257	265
Leaving as the tractive and internal resistance of the engine without load	579	426	457

		Lbs. per ton of eng.
In round figures, we may deduce from the preceding, for locomotive resistances in lbs. per ton, of engines of the American type (in which head-resistance would be a larger proportion than in more powerful engines)	Atmospheric	3.0
	Rolling friction, light	5.0
	Internal " "	5.0
	" " increase due to load	5.0
	Total	18.0
The average of the train behind engine is, say		6.75
Excess of engine resistance, lbs. per ton of engine		11.25

This engine excess, when distributed through the entire train (of 35 loaded cars) makes a difference, as shown above, of only (average, 0.74, 0.70, 0.77), say ¾ lb. per ton.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

TABLE 148.—*Continued.*

Taunton Locomotive Works.

16″ × 24″ CYLINDERS.		17″ × 24″ CYLINDERS.	
Year.	Weight—Lbs.	Year.	Weight—Lbs.
1848*.....	50,000*	1850*.....	57,000*
1857†.....	58,000†	1857......	67,700
1859†.....	52,000†	1865......	67,000
1860†.....	54,000†	1882......	78,400
1861......	62,400	1883......	80,000
1880......	70,000	1884......	90,000
1883......	82,000	1885......	91,000
1884......	83,000		
* 16″ × 20″ cylinders. † 16″ × 22″ "		* 17″ × 20″ cylinders.	

See also Tables 127–130.

Most of the striking change shown in this table is accounted for by the gradual increase in boiler pressure carried. See par. 605.

strikingly. After allowing its full weight to the effect of the increase in boiler pressure carried, it is clear that there is no tendency toward using larger cylinders for the sake of being able to cut off earlier.

THE THEORETICAL GAIN BY EXPANSION.

574. Under "Mariotte's Law" (given in any text-book on physics) the volume of a gas is inversely as the pressure, so that if the gas has expanded into twice the volume it exerts half the pressure, etc.

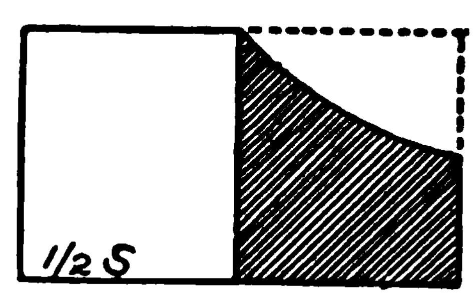

FIG. 124.

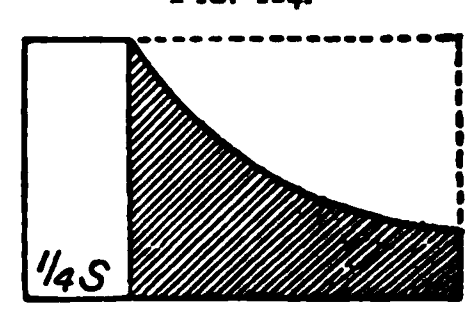

FIG. 125.—THE RATIO OF THE SHADED PORTION TO THE UNSHADED RECTANGLE INDICATES THE THEORETICAL GAIN BY EXPANSION.

In "cutting off" steam at some point in the stroke, say half- or quarter-stroke, the steam in the cylinder expands according to this law (theoretically), and thus continues to push the piston before it with a gradually decreasing pressure as the interior volume increases, until at the end of the stroke the pressure is (or ought to be, with a perfect gas) just half or a quarter of the initial boiler pressure. A perfect indicator-diagram of such a stroke would have the form of Figs. 124, 125, the bounding curve being a hyperbola, as in Fig. 97. The shaded portion in these cuts represents what is gained by expansion, or ought to be.

575. But steam is not affected in precisely the same way as a perfect gas by changes of pressure and volume; and, moreover,

Table [illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
			[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Table [illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.0 p.c.

its expansion in the cylinder means the doing of WORK,—which means loss of heat,—which means loss of pressure,—which means a reduction in the work done; so that the true curve which should bound a theoretical diagram (which was called by Prof. Rankine an "adiabatic" curve) and the precise theoretical gain which should result from expansion is all but incapable of rigorous analysis. It has been shown that there is little error of practical moment in assuming that the steam expands in accordance with Mariotte's law, and it is laid down that it does so, without qualification, in some popular text-books; but we may as well use the correct theoretical quantities, as given in Prof. Chas. A. Smith's "Steam Using, or Steam-Engine Practice," by whom they were carefully determined from a large diagram. According to these figures, if we can conceive of a non-conducting cylinder we obtain the following figures, abbreviated from Table 149. The boiler pressure assumed is 120 lbs. per square inch above the atmosphere, but the results are but little affected by the initial boiler pressure, as will be evident from Table 150:

576. If steam be cut off at

Full stroke,	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$
The theoretical gain by expansion (Table 149) is as						
1.000	1.285	1.459	1.666	1.905	2.278	2.854
Whereas by Mariotte's law it is somewhat less, viz.:						
1.000	1.261	1.425	1.616	1.837	2.139	2.511
The theoretical pounds of steam required, per horse-power per hour, are						
31.3	23.8	21.4	18.8	16.4	15.4	11.0
And the mean effective pressure in pounds per square inch, allowing a certain minimum of 1 (1.3) lb. per square inch for unavoidable back pressure, should be						
119.	115.	107.	96.	91.	60.7	32.1

In a condensing engine the mean effective pressure should be some 12 lbs. more than this in each case, representing the gain by the additional complication of the condensing apparatus.

577. The locomotive engine is run, as an average, cutting off at half-stroke; it is rarely possible to cut off at less than quarter-stroke (6 inches, with a 24-inch cylinder) or at more than seven-eighths stroke. The maximum gain, therefore, which it ought in theory to result from expansion is only some 67 per cent, and if we had an engine so perfect that it could utilize without loss of heat the entire expansive energy of the steam, so as to discharge it into the air at atmospheric pressure, it will be seen (Table 149) that the utmost possible economy would be about four times that of using steam at full stroke; so that at best only some $82 \times 4 = 328$ heat-units out of 1159, or 28.3 per cent, could be utilized. The utmost that is actually realized in the very finest marine engines burning 1.3 to 1.5 lbs. of coal per horse-power per hour is some 16 or 18 per cent of the heat put into the steam, which is perhaps three fourths of that which comes out of the coal.

578. [illegible] engine as we have been discussing which will give a diagram [illegible] are practically out of the question. It is impossible [illegible] pressure of steam instantly, and it is impossible to retain the steam [illegible] within the cylinder until the very end of the stroke or leave the opposite end entirely without resisting pressure to absorb the momentum of the reciprocating parts of the engine, which would speedily pound itself to pieces. The [illegible] so that the steam is admitted in front of the piston [illegible] a little before the end of the stroke and the [illegible] the meaning of which is explained in [illegible] the steam-engine, resulting in giving to the theoretical diagram [illegible] steam-engine as actually worked in practice the form shown [illegible] in which the pressure does not remain full during admission [illegible] by any means true, the lower or exhaust line [illegible] pressure, and the lower left-hand corner is not [illegible] angle as in Fig. [illegible] but much rounded by compression at the end of the stroke. Not all of this compression is lost [illegible] some of the work done in giving motion to the reciprocating parts [illegible] amount [illegible] it is needless to [illegible] now summarize the various other and far more important [illegible] and see by the records of experience what their aggregate [illegible]

579. [illegible] sources of loss of [illegible] efficiency in the locomotive [illegible]

[illegible] that the pressure in the cylinder is [illegible]

[illegible] These sources of [illegible] more serious at [illegible] and the last [illegible] occurs at all [illegible]

[illegible] have so important an effect on the tractive [illegible] are separately discussed in par. 58[illegible]. [illegible] nearly all the indicator-diagrams [illegible]

580. [illegible] entrained water in the steam has to be evaporated; a loss [illegible] defects of the boiler than to the [illegible] found in his carefully conducted experiments that [illegible] of the apparent evaporations was really only [illegible] mechanically with the steam at the same sensible [illegible] unevaporated. Other tests show 3 and 5 per [illegible] and some none, but it is probably rarely less than 5 per cent. This

means that with the half-pound or more of steam which enters the cylinder at each stroke, from half an ounce to an ounce of hot water is injected with it. The loss involved is not simply the 300° of heat which have been given to the water, but as soon as the pressure and temperature fall during expansion and exhaust this hot water flashes into steam, absorbing the necessary heat for that purpose from the hotter walls of the cylinders, and having all the practical effect upon the temperature of the walls of the cylinder of a spray of cold water at every stroke.

581. 4. *A constant radiation of heat from the metallic cylinder* (only a part of which is lagged) and its connected parts into the surrounding air, so that a certain small fraction of the steam must be condensed at each stroke to supply this loss.

Perhaps Figs. 126 to 130 are as good direct evidence as any of the very great loss which results from this cause. It will be seen from them that the mere effect of leaving off the cover from one end of the cylinder was to make a very noticeable reduction in the effective average pressure. It is to be remembered in comparing these two diagrams that this "cover," the removal of which caused so great a difference, is nothing but a thin plate of metal, in direct metallic contact with the cylinder at many points, and including only a thin space of dead air between them. We are not, therefore, comparing a well-protected with a badly-protected cylinder, but a badly-protected with a worse-protected one.

It is not probable that the absolute loss of heat, measured merely by heat-units, is anything like as great from the cylinders and connected parts as from the boiler; but each unit of heat subtracted from the boiler can be replaced by another without any indirect loss, whereas after the steam has once entered the steam-chest and cylinder the loss of a few units of heat, by reducing the pressure, means the loss of much of the efficiency of what heat is left.

582. 5. Still more important than direct external radiation is the phenomenon known as *internal radiation into the exhaust steam*. The steam enters at 120 to 140 lbs. pressure, corresponding to 350° to 360° Fahr. It leaves the cylinder at 4 to 7 lbs. pressure and 225° to 230° Fahr. In entering it heats the interior walls of the cylinder, which it finds at perhaps 250° Fahr., to nearly its own temperature, and some steam is condensed thereby, reducing by so much the pressure and the work done. When the exhaust opens and the temperature of the steam falls these hot walls radiate their heat back again into the steam, wasting it by re-evaporating the vapor carried out in the exhaust. Thus a certain large fraction of the heat passes *through* the cylinder, by a kind of side-path, without really taking any part in the work done *in* the cylinder, as a leaky flume might let a portion of the water past a water-wheel without its doing any work on it.

TABLE 148.—*Continued.*

Taunton Locomotive Works.

16″ × 24″ CYLINDERS.		17″ × 24″ CYLINDERS.	
Year.	Weight—Lbs.	Year.	Weight—Lbs.
1848*.....	50,000*	1850*.....	57,000*
1857†.....	58,000†	1857......	67,700
1859†.....	52,000†	1865......	67,000
1860†.....	54,000†	1882......	78,400
1861......	62,400	1883......	80,000
1880.. ...	70,000	1884......	90,000
1883......	82,000	1885......	91,000
1884......	83,000		
* 16″ × 20″ cylinders. † 16″ × 22″ "		* 17″ × 20″ cylinders.	

See also Tables 127–130.

Most of the striking change shown in this table is accounted for by the gradual increase in boiler pressure carried. See par. 605.

strikingly. After allowing its full weight to the effect of the increase in boiler pressure carried, it is clear that there is no tendency toward using larger cylinders for the sake of being able to cut off earlier.

THE THEORETICAL GAIN BY EXPANSION.

574. Under "Mariotte's Law" (given in any text-book on physics) the volume of a gas is inversely as the pressure, so that if the gas has expanded into twice the volume it exerts half the pressure, etc.

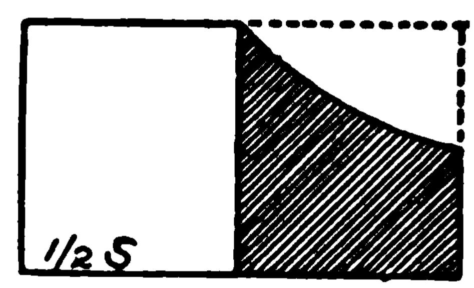

FIG. 124.

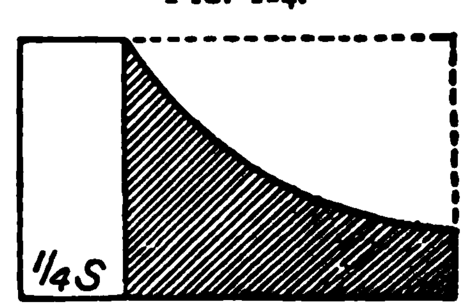

FIG. 125.—THE RATIO OF THE SHADED PORTION TO THE UNSHADED RECTANGLE INDICATES THE THEORETICAL GAIN BY EXPANSION.

In "cutting off" steam at some point in the stroke, say half- or quarter-stroke, the steam in the cylinder expands according to this law (theoretically), and thus continues to push the piston before it with a gradually decreasing pressure as the interior volume increases, until at the end of the stroke the pressure is (or ought to be, with a perfect gas) just half or a quarter of the initial boiler pressure. A perfect indicator-diagram of such a stroke would have the form of Figs. 124, 125, the bounding curve being a hyperbola, as in Fig. 97. The shaded portion in these cuts represents what is gained by expansion, or ought to be.

575. But steam is not affected in precisely the same way as a perfect gas by changes of pressure and volume; and, moreover,

TABLE 149.

THEORETICAL EFFICIENCY OF STEAM, EXPANDED IN NON-CONDUCTING CYLINDERS, INVOLVING NO WASTE OF HEAT.

[Rearranged from "Steam Using, or Steam-Engine Practice," by Prof. Chas. A. Smith.]

Boiler pressure assumed at 120 lbs. per sq. in. above atmosphere.

CUT-OFF.	Theoret. Pounds Steam Per Horse-power Per Hour (120 lbs. over Atmos.)	Theoret. Gain by Expansion. Full Stroke = 1.00 (absolute press.)	MEAN EFFECTIVE PRESSURE PER SQ. IN.		Gain Per Cent by Condensing.
			Non-condensing.	Condensing.	
Full Stroke..	31.3	1.000	119	131	10.1
$\frac{3}{4}$ " ..	23.8	1.285	115	127	10.4
$\frac{5}{8}$ " ..	21.4	1.459	107	119	11.2
$\frac{1}{2}$ " ..	18.8	1.666	96	108	12.5
$\frac{3}{8}$ " ..	16.4	1.905	81	93	14.8
$\frac{1}{4}$ " ..	15.4	2.278	60.7	72.7	19.8
$\frac{1}{8}$ " ..	11.0	2.854	32.1	44.1	37.4
$\frac{1}{10}$ " ..	10.3	3.034	25.0	37.0	48.0
$\frac{1}{20}$ " ..	8.8	3.547	7.9	19.9	151.8
$\frac{1}{30}$ " ..	8.2	3.835	1.3	13.3	923

The mean effective pressure is computed by assuming a minimum back pressure of 1.3 lbs. per sq. in. above the atmosphere in non-condensing engines, and a minimum back pressure of 4 lbs. (or 12 lbs. gain by condensing) in condensing engines.

TABLE 150.

THEORETICAL ECONOMY OF STEAM FROM CARRYING HIGHER BOILER PRESSURES.

[Abstracted from "Steam Using, or Steam-Engine Practice," by the late Prof. Chas. A. Smith.]

PRESSURE ABOVE ATMOSPHERE, POUNDS PER SQ. IN.	POUNDS OF DRY STEAM, IF WORKED IN A PERFECTLY NON-CONDUCTING CYLINDER PER TOTAL HORSE-POWER PER HOUR, WITH CUT-OFF AT—				
	Full Stroke.	$\frac{2}{3}$ Stroke.	$\frac{1}{2}$ Stroke.	$\frac{1}{4}$ Stroke.	$\frac{1}{10}$ Stroke.
0.........	35.7	24.9	21.4	15.7	11.7
20.........	33.7	23.6	20.3	14.9	11.1
60.........	32.5	22.7	19.5	14.3	10.7
100.........	31.7	22.2	19.0	13.9	10.4
140.........	30.9	21.6	18.5	13.6	10.2
180.........	30.5	21.4	18.3	13.4	10.1
220.	30.2	21.1	18.1	13.3	10.0
Per cent of Economy between 20 and 220 lbs. Press.	11.6 p. c.	11.7 p. c.	12.2 p. c.	12.0 p. c.	11.0 p. c.

its expansion in the cylinder means the doing of WORK,—which means loss of heat,—which means loss of pressure,—which means a reduction in the work done; so that the true curve which should bound a theoretical diagram (which was called by Prof. Rankine an "adiabatic" curve) and the precise theoretical gain which should result from expansion is all but incapable of rigorous analysis. It has been shown that there is little error of practical moment in assuming that the steam expands in accordance with Mariotte's law, and it is laid down that it does so, without qualification, in some popular text-books; but we may as well use the correct theoretical quantities, as given in Prof. Chas. A. Smith's "Steam Using, or Steam-Engine Practice," by whom they were carefully determined from a large diagram. According to these figures, if we can conceive of a non-conducting cylinder we obtain the following figures, abbreviated from Table 149. The boiler pressure assumed is 120 lbs. per square inch above the atmosphere, but the results are but little affected by the initial boiler pressure, as will be evident from Table 150:

576. If steam be cut off at

Full stroke,	¾	⅝	½	⅜	¼	⅛
The theoretical gain by expansion (Table 149) is as						
1.000	1.285	1.459	1.666	1.905	2.278	2.854
Whereas by Mariotte's law it is somewhat less, viz.:						
1.000	1.261	1.425	1.616	1.837	2.139	2.511
The theoretical pounds of steam required, per horse-power per hour, are						
31.3	23.8	21.4	18.8	16.4	15.4	11.0
And the mean effective pressure in pounds per square inch, allowing a certain minimum of 1 (1.3) lb. per square inch for unavoidable back pressure, should be						
119.	115.	107.	96.	91.	60.7	32.1

In a condensing engine the mean effective pressure should be some 12 lbs. more than this in each case, representing the gain by the additional complication of the condensing apparatus.

577. The locomotive engine is run, as an average, cutting off at half-stroke; it is rarely possible to cut off at less than quarter-stroke (6 inches, with a 24-inch cylinder) or at more than seven-eighths stroke. The maximum gain, therefore, which it ought in theory to result from expansion is only some 67 per cent, and if we had an engine so perfect that it could utilize without loss of heat the entire expansive energy of the steam, so as to discharge it into the air at atmospheric pressure, it will be seen (Table 149) that the utmost possible economy would be about four times that of using steam at full stroke; so that at best only some 82 $\times 4 = 328$ heat-units out of 1159, or 28.3 per cent, could be utilized. The utmost that is actually realized in the very finest marine engines burning 1.3 to 1.5 lbs. of coal per horse-power per hour is some 16 or 18 per cent of the heat put into the steam, which is perhaps three fourths of that which comes out of the coal.

578. Such engines as we have been discussing, which would give a diagram similar to Figs. 124, 125, are practically out of the question. It is impossible to admit a full pressure of steam instantly, and it is impossible to retain the steam shut up within the cylinder until the very end of the stroke or leave the opposite end entirely without resisting pressure to absorb the momentum of the approaching piston, or the engine would speedily pound itself to pieces. The valve is therefore given a LEAD so that the steam is admitted in front of the piston and released from behind it a little before the end of the stroke, and the combined effect of the lead and the LAP (the meaning of which is explained in any treatise on the steam-engine) results in giving to the theoretical diagram of a high-pressure steam-engine, as actually worked in practice, the form shown in Figs. 126 to 148, in which the pressure does not remain full during admission, the expansion curve is not by any means true, the lower or exhaust line is not by any means at a zero pressure, and the lower left-hand corner is not by any means a sharp angle, as in Figs. 124, 125, but much rounded by compression at the end of the stroke. Not all of this compression is lost, it is true, since it saves some of the work done in giving motion to the reciprocating parts; but how much the theoretical loss amounts to it is needless to inquire, for we may now summarize the various other and far more important sources of loss, and see by the records of experience what their aggregate amounts to.

579. The chief sources of loss of cylinder efficiency in the locomotive engine are those numbered 1 to 8 below:

1. *The steam is wire-drawn*, so that its pressure in the cylinder is never equal to that of the boiler, and often 10 and even 20 lbs. below it.

2. *The steam-ports are not large enough to admit steam as fast as the piston moves*, especially if it be moving fast. Both of these sources of loss are, owing to the peculiarities of the link-motion, more serious at high speed and with early cut-offs, and the last one hardly occurs at all under other circumstances.

These two causes together have so important an effect on the tractive power of engines that they are separately discussed below (par. 587). Their effect is illustrated practically in nearly all the indicator-diagrams which follow.

580. 3. *All entrained water in the steam has to be evaporated*; a loss, however, more properly chargeable to defects of the boiler than to the cylinder. M. Marié found in his carefully conducted experiments that something over 10 per cent of the apparent evaporations was really only vapor carried along mechanically with the steam at the same sensible temperature, 350°, but unevaporated. Other tests show 3 and 5 per cent, and some none, but it is probably rarely less than 5 per cent. This

means that with the half-pound or more of steam which enters the cylinder at each stroke, from half an ounce to an ounce of hot water is injected with it. The loss involved is not simply the 300° of heat which have been given to the water, but as soon as the pressure and temperature fall during expansion and exhaust this hot water flashes into steam, absorbing the necessary heat for that purpose from the hotter walls of the cylinders, and having all the practical effect upon the temperature of the walls of the cylinder of a spray of cold water at every stroke.

581. 4. *A constant radiation of heat from the metallic cylinder* (only a part of which is lagged) and its connected parts into the surrounding air, so that a certain small fraction of the steam must be condensed at each stroke to supply this loss.

Perhaps Figs. 126 to 130 are as good direct evidence as any of the very great loss which results from this cause. It will be seen from them that the mere effect of leaving off the cover from one end of the cylinder was to make a very noticeable reduction in the effective average pressure. It is to be remembered in comparing these two diagrams that this "cover," the removal of which caused so great a difference, is nothing but a thin plate of metal, in direct metallic contact with the cylinder at many points, and including only a thin space of dead air between them. We are not, therefore, comparing a well-protected with a badly-protected cylinder, but a badly-protected with a worse-protected one.

It is not probable that the absolute loss of heat, measured merely by heat-units, is anything like as great from the cylinders and connected parts as from the boiler; but each unit of heat subtracted from the boiler can be replaced by another without any indirect loss, whereas after the steam has once entered the steam-chest and cylinder the loss of a few units of heat, by reducing the pressure, means the loss of much of the efficiency of what heat is left.

582. 5. Still more important than direct external radiation is the phenomenon known as ***internal radiation into the exhaust steam***. The steam enters at 120 to 140 lbs. pressure, corresponding to 350° to 360° Fahr. It leaves the cylinder at 4 to 7 lbs. pressure and 225° to 230° Fahr. In entering it heats the interior walls of the cylinder, which it finds at perhaps 250° Fahr., to nearly its own temperature, and some steam is condensed thereby, reducing by so much the pressure and the work done. When the exhaust opens and the temperature of the steam falls these hot walls radiate their heat back again into the steam, wasting it by re-evaporating the vapor carried out in the exhaust. Thus a certain large fraction of the heat passes ***through*** the cylinder, by a kind of side-path, without really taking any part in the work done ***in*** the cylinder, as a leaky flume might let a portion of the water past a water-wheel without its doing any work on it.

583. The loss from this source may amount, it is alleged by D. K. Clark,* to anywhere from 11 to 42 per cent, the latter only with very short cut-offs. As its amount increases (1) with the range of temperature and (2) with the time of exposure, it is less at high speeds or with late cut-offs. Mr. Clark adds:

"These results sufficiently explain how it happens that expansive working in locomotives, especially in outside cylinder engines, is in practice carried out to such a limited extent. We have rarely found (1850) on the Caledonian Railway—a line stocked with outside-cylinder locomotives—that a cut-off materially less than 30 per cent is voluntari' y adopted by the engine drivers. In their own words, they 'lose as much as ..ey gain' if they endeavor to work with a suppression much less than 30 pe cent."

This still (1886) remains as true for American practice as when Mr. Clark first wrote it, except that for 30 per cent we should read $37\frac{1}{2}$ or perhaps 40 per cent. But little gain results in practice from cutting off shorter, if any; and accordingly the all but universal rule, where parts of the road are struck which require only a light power, is to throttle the steam, and reduce its initial pressure even so much as one half rather than attempt to cut off earlier. While this practice is often pushed too far, it is better than attempting to cut off at less than three-eighths stroke or more, except at very high speeds.

584. Prof. Charles A. Smith, who studied this question with great care as respects stationary engines, lays down the approximate rule, as the average result of some 49 tests, that the average loss may be estimated at 3.6 lbs. of excess water (i.e., steam) *per hour*, per foot of piston diameter per deg. Fahr. difference of initial and final temperature. This is on the assumption that time is so important an element in the amount of this loss that the number of strokes per hour is unimportant, which is far from literally true. At this rate, assuming an average range of temperature of 100° Fahr. in the cylinder, there would be some 500 lbs. of steam per hour condensed internally in a 17-in. cylinder, and some 600 lbs. in a 20-in. cylinder.

585. 6. *The back pressure*, amounting to anywhere from 4 to 7, or even (in bad practice) 10 or 12 lbs, per sq. in., or to from 2 to 20 per cent of the total power developed. It is caused chiefly (until compression begins at the end of the stroke) by the contraction of the exhaust-nozzles to produce the draft which keeps up the fires, but in part by the impossibility of the steam escaping quickly enough without a considerable pressure to drive it out.

7. *The clearance spaces*, already alluded to, waste a considerable amount of steam, from 7 to 9 per cent when cutting off at full stroke. but less when cutting off short, since the steam in the clearance spaces expands with the rest and does a certain amount of work in that way.

* "Manual for Mechanical Engineers," p. 880.

586. 8. *The energy communicated to the piston and connected parts* during the first half of the stroke, in order to give it a velocity of from $\frac{1}{4}$ to $\frac{1}{3}$ $\left(\frac{\text{stroke}}{\text{diam. of drivers}}\right)$ of the train, and then surrendered again during the last part of the stroke, is in great part lost, so far as useful work is concerned. It is expended on that portion of the exhaust which is shut up in the cylinder by the preclosure of the valve and practically reconverted into heat, by raising the steam so shut up from a pressure of perhaps 4 lbs. and temperature of 225° to perhaps 120 lbs. and 350°.

587. The aggregate effect of these differences is to very greatly decrease the TRACTIVE FORCE which it is mechanically possible for the locomotive to exert at the higher working speeds, but not therefore the HORSE-POWER which the engine is capable of exerting, nor (within reasonable limits) the economy with which that power is obtained. This is especially true of the first two causes (par. 579), which we may now consider, in connection with diagrams which will show more clearly the exact limits of the effect.

588. Under the most favorable circumstances, with the throttle wide open and speed slow, the pressure in the steam-chest hardly ever rises within 5 lbs. of the boiler pressure, and this is still further reduced when the steam enters the cylinders, so that the initial pressure, with all the assistance of compression, is rarely within 10 lbs. of the boiler pressure. When the throttle is only partially open (Figs. 127, 128) or the speed is very high, or especially with both together, there is a still further and great loss of pressure, often more than one half.* Throttling is also a very common resort in preference to using an earlier cut-off, as the engine runs more smoothly and, practical experience shows, with but little more waste of steam.

589. In all such reductions of initial pressure as those alluded to there is a certain theoretical loss, but only a small one. It is greatly exaggerated in popular belief (as well as in certain text-books of excellent standing) by confusing a loss of mere *pressure*, or pounds of traction, with a loss of energy. The tractive force in pounds is undoubtedly reduced in rather more than constant ratio with the reduction of initial pressure; but then, if this occurs only when a larger tractive force is not required or cannot be sustained by the boiler, this is in itself of no importance, and as respects the amount of WORK which can be done with the same quantity of steam, it is but very little affected by the reduction of pressure, either theoretically or practically. Theoretically, the amount

* On some diagrams taken on an express passenger engine on the Philadelphia & Reading Railroad, taken at 65 miles per hour, it was found that the average effective pressure was actually less when cutting off at 10 in. than when cutting off at 5 in., although the amount of steam used was far greater.

of steam required per horse-power per hour for pressures varying by [illegible] lbs. per square inch:—

Pressure above atmosphere	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Lbs. steam per H. P. per hour	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

A difference which [illegible] is worth much discussion, unless without [illegible] any advantage. Practically it has been shown in many experiments of late years, and especially in a remarkable series of experiments by Mr. Dela[illegible], engineer-in-chief of the mines at Creusot, France,* that "the difference in economy between steam of [illegible] lbs. and steam of [illegible] lbs. is very small, and when we take the generation of steam into consideration, as well as its use, the lower pressure is the more economical."

Similarly Mr. D. K. Clark,† who is certainly one of the most careful students of the theory and practice of the locomotive, concludes that "as the loss from wire-drawing is of little or no moment, and as wire-drawing was, to some degree, equivalent to an earlier cut-off, it might even prove advantageous in point of economy."

590. But wire-drawing does very seriously reduce the tractive power of engines. When it occurs only when the speed rises considerably above ordinary working speeds, say 28 miles per hour in freight engines, or 50 miles per hour in passenger engines, this is no great disadvantage, because such speeds are only desired when the grades are favorable or train light, and much tractive power is not required; but when it occurs to any material extent with late cut-offs at ordinary working speeds of 12 to 15 miles per hour, it is more objectionable.

591. Unfortunately, experiment seems to indicate quite uniformly that it is rather the rule than the exception for freight engines to show a considerable reduction in cylinder efficiency even at their lower working speeds, so that speeds as low as it is safe to use without danger of the train being brought to a stop by slight additional resistance from curves, grades, head winds, or bad track, do cause a very material decrease of available average cylinder pressure; and hence the engine cannot possibly utilize its available ultimate tractive power—i.e., very nearly slip its wheels—at any practicable working speed, however low, although the difference is small compared with the effect of further increase of speed.

592. That it is so is shown, perhaps, as conclusively as in any other way, in the following diagrams (Figs. 134 to 139) of the engine whose performance is

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* *Annales Industriel*, Feb., 1885.

† "Manual for Mechanical Engineers," p. 879.

recorded in Table 146 and Fig. 123 (par. 571). The same thing appears in the diagrams accompanying Mr. Stroudley's paper (par. 570 and Fig. 122), where,

With a cut-off of	$\frac{1}{4}$	$\frac{1}{4}$
At a speed in miles per hour of	12 m.	30 m.
And *steam-chest* pressure of	140 lbs.	130 lbs.
The average pressure was	74.8 lbs.	57.2 lbs.
The horse-power being	262	502

At 12 miles per hour, with 60 per cent cut-off and 125 lbs. *steam-chest* pressure (boiler pressure full 5 lbs. more), the average cylinder pressure was 95.4 lbs., whereas at 4 miles per hour an average of about 85 per cent of the boiler pressure was obtained in the cylinder—about the best which is ever possible.

593. That this should occur at high speeds is practically unavoidable, but that it should occur at slow speeds of less than 15 miles per hour is in no respect a mechanical necessity, nor does it require any radical modification of existing engines to cure it, whenever it appears desirable, but merely some slight modification of the valves. Some engines do not show it, but more do. The chief reason why it is not done is that no particularly useful end would be served thereby, since the imperfections of the gradients and of the locomotive serve to justify each other, by destroying to a very large extent the advantage of remedying one without the other. It is important that the true nature of the difficulty should be clearly understood.

594. The largest tractive pulls, by far, on nearly all railways, are exerted in getting trains under way from stopping-places on unfavorable grades or curves. There are few roads indeed, and those only having very heavy grades, on which the traction between stations is the heaviest. So long as this is so, the need is not felt that an engine should be able to exert something like its maximum pull between stations at fair working speeds, and as a very natural consequence their valves are not arranged so that they can do so.

Now, as a rule, a large part of the additional tractive force demanded at stations may be saved by more careful study of the grades at stations; but if this be done, and it be attempted to increase the trains correspondingly, the only effect with very many engines will be that they will either "stick on the grades" or lose so much time that to utilize the improvement at stations will be impracticable. For the same reason, if it be endeavored to find out where the engines are really most taxed it will often be difficult to do so. They slip their wheels most at stations, but "they have all they can do" to make time on the grades; so that from the bare face of the statements there will be little to show where the weakest point is,

(*see page* 478)

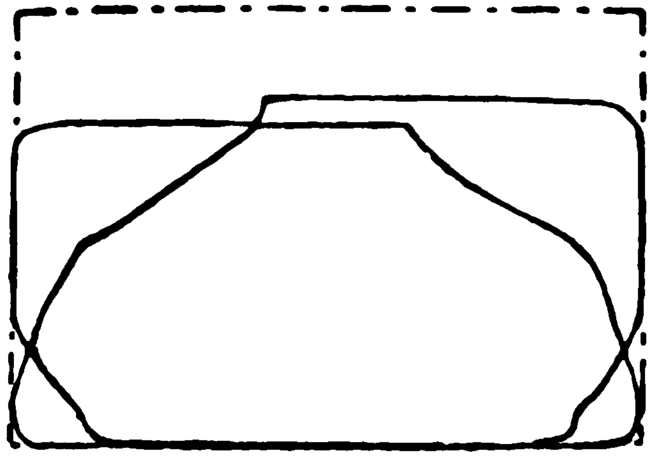

FIG. 126.

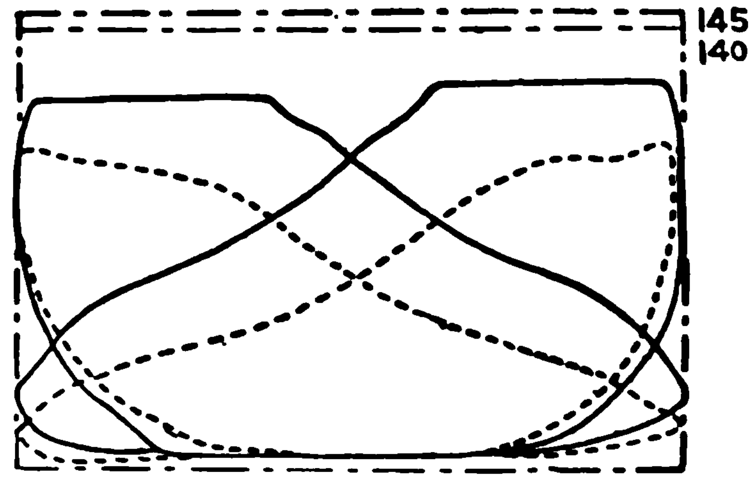

FIG. 127.

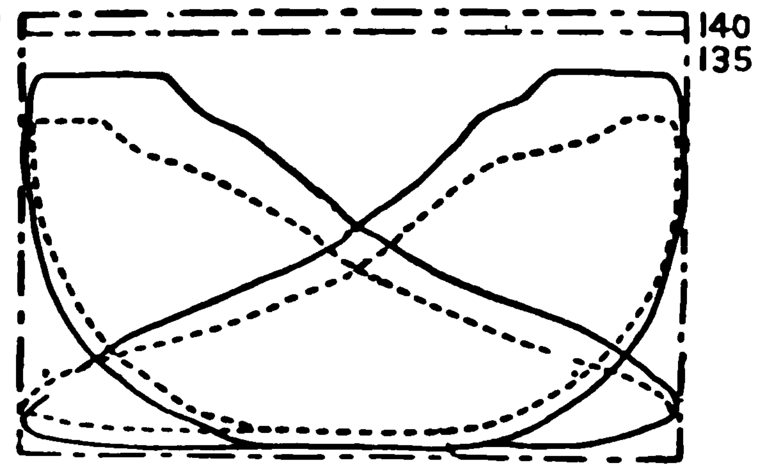

FIG. 128.

	FIG. 126.	FIG. 127. ———	FIG. 127. ·········	FIG. 128. ———	FIG. 128. ·········
Boiler pressure	140 lbs.	140 lbs.	145 lbs.	140 lbs.	135 lbs.
Cut-off	14½ in.	10 in.	10 in.	8 in.	8 in.
Throttle open	....	½	¼	½	½
Speed	0 +	25.5 m.	30.3 m.	29.1 m.	36.4 m.
Av. cylinder pressure...	84.8 lbs.	76.5 lbs.	48.1 lbs.	61.8 lbs.	44.9 lbs.
Indicated horse-power..	....	595	444	549	498
Loss initial pressure....	31 lbs.	17 lbs.	37 lbs.	17 lbs.	32 lbs.

Fig. 126 was taken when the engine was starting, with the cylinders and passages cold. The initial pressure in the cylinder is no less than 27 lbs. below the boiler pressure at one end of the cylinder, and 36 lbs. at the other. The *difference* between the pressures at the two ends of the cylinder is due to the extra condensation caused by the absence of the front cylinder-cover casing. The effect of this to reduce the initial pressure at one end is very remarkably shown in all the four succeeding diagrams, Figs. 127 to 130.

The immense effect of even moderate difference of moderate speed to decrease average pressure is clearly shown by comparison of the dotted and solid diagrams in Figs. 127 and 128:

	Fig. 127.	Fig. 128.
An increase of speed of	25.5 to 30.3 = 4.8	29.1 to 36.4 = 7.3
Caused a reduction of average pressure of	76.5 to 48.1 = 28.4	61.8 to 44.9 = 16.9

In Fig. 127 there was a difference in the throttle, which accounts for about half the contrast, but none in Fig. 128.

Figs. 126 to 133 were taken in some tests on the Cincinnati, New Orleans & Texas Pacific (Cincinnati Southern) Railway, from a fine Baldwin passenger engine of the following dimensions:

Cylinders	18 × 24 in.	Ports, steam	16 × 1¼ in.
Drivers	68 in.	Ports, exhaust	16 × 2¼ in.
Weight, on drivers	60,000 lbs.	Exhaust nozzle	3¼ in.
Weight, total	90,000 lbs.	Heating surface, tubes	1,325 sq. ft.
Tractive force per pound of av. press. in cylinder (Table 151)	114.4 lbs.	Heating surface, fire-box	133 sq. ft.
Valves, Allen-Richardson: Lap, ⅞ in.; lead, $\frac{1}{16}$ in.		Heating surface, Total	1,458 sq. ft.
		Grate area	17 sq. ft.

The train hauled consisted of 8 cars, weighing 480,000 lbs.

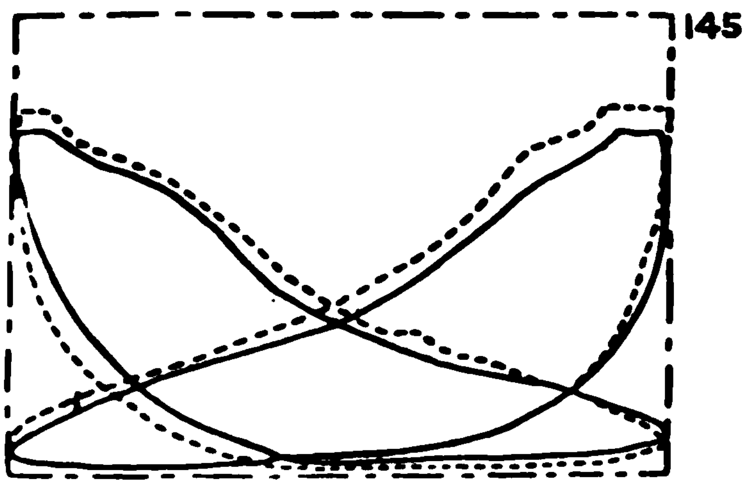

FIG. 129.

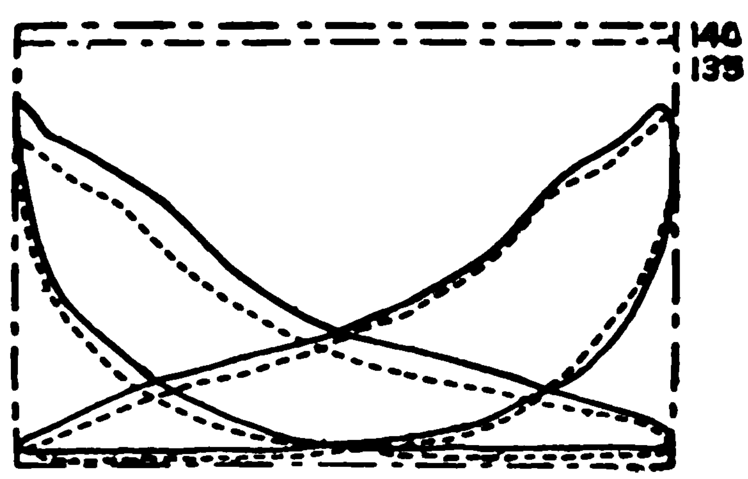

FIG. 130.

	FIG. 129. ———	FIG. 129. ········	FIG. 130. ———	FIG. 130. ········
Boiler pressure	145 lbs.	145 lbs.	140 lbs.	135 lbs.
Cut-off	8 in.	8 in.	6 in.	4 in.
Throttle open	⅛	⅛	⅛	¼
Speed	53.4 m.	45.0 m.	54.6 m.	55.9 m.
Av. cylinder pressure	37.2 lbs.	44.3 lbs.	32.5 lbs.	28.0 lbs.
Indicated horse-power	583	608	541	477
Loss initial pressure	32 lbs.	22 lbs.	24 lbs.	26 lbs.

Figs. 129, 130 show the same effect of speed as Figs. 126–128 very forcibly, both by comparison of the full and dotted diagrams and (still more forcibly) by comparing the solid diagrams in Figs. 128 and 129, which may be said to be taken under precisely similar circumstances (balancing difference in throttle against difference in boiler pressure) except that

	Fig. 128.		Fig. 129.
Speed was	29.1		53.4
Reducing average pressure from	61.8	to	37.2
Yet that this does no real harm to hauling capacity is evident from the fact that the horse-power at which the engine was working increased from	549	to	583

Comparing the solid Fig. 131 with the solid Fig. 127 we see that the combined effect of 5 lbs. higher boiler pressure, 4 ins. longer cut-off, and a throttle ¾ instead of ⅛ open, gave only a slightly higher average pressure (6.8 lbs.), indicating that the slight difference of 0.8 mile per hour in speed very largely counterbalanced all these advantages. Fig. 132, contrasted with the dotted Fig. 129, illustrates a truth which might be proved in many other ways, that after the speed gets fairly high it does little or no good to

admit more steam to the cylinders. The greater average pressure which should be gained is used up in back pressure and wire-drawing. See also Figs. 133–135.

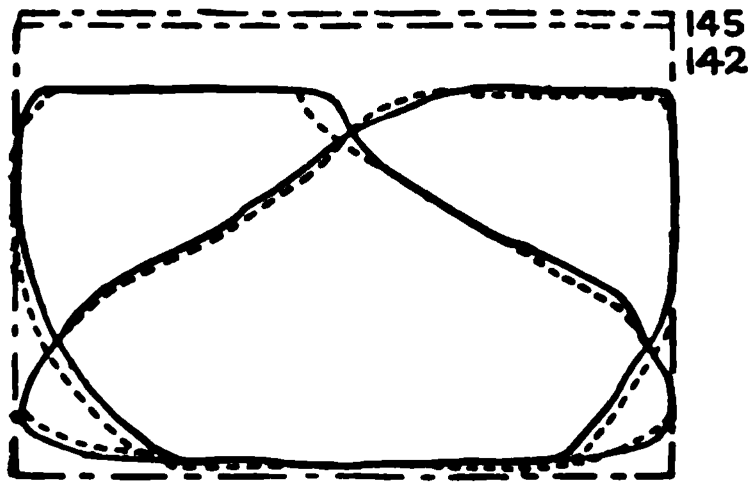

FIG. 131.

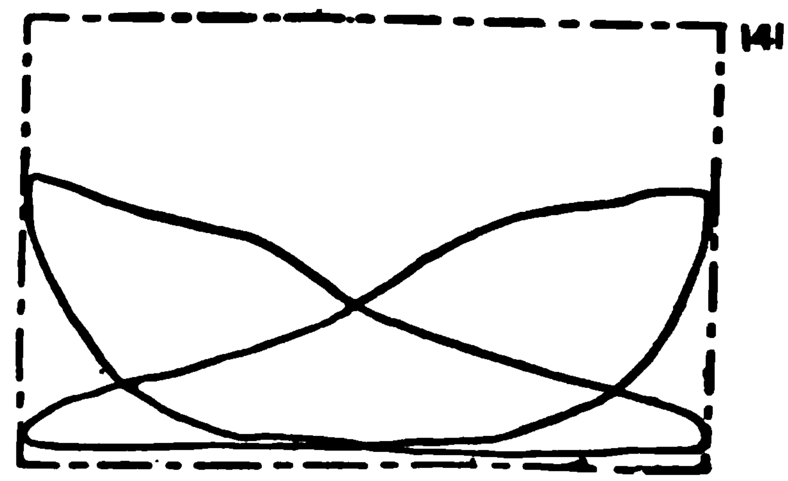

FIG. 132.

	FIG. 131.		FIG. 132.
	———	....	
Boiler pressure......	145 lbs.	142 lbs.	141 lbs.
Cut-off..............	14 in.	14 in.	11 in.
Throttle open........	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{3}$
Speed...............	26.3 m.	24.3 m.	46.9 m.
Av. cylinder pressure.	83.3 lbs.	81.3 lbs.	37.9 lbs.
Indicated horse-power	668	603	542
Loss initial pressure..	24 lbs.	20 lbs.	50 lbs.

nor to indicate that the one arises from excessive demand on the tractive power, which is remediable only by changing the grades, while the other is caused by deficiency of cylinder power only, which is remediable for the most part by trivial changes in the valves.

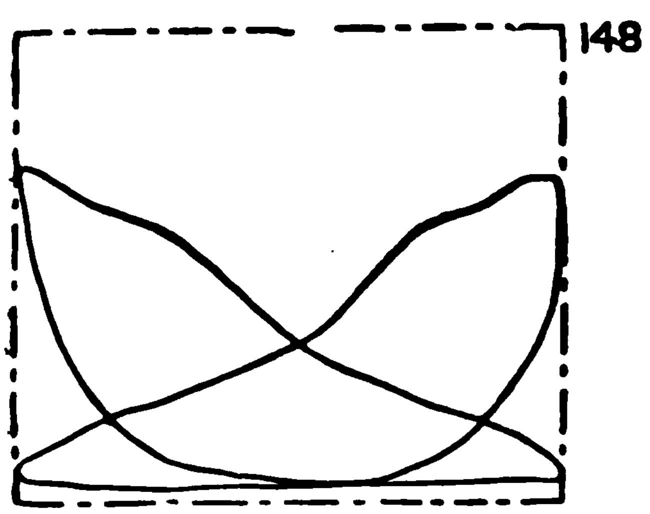

FIG. 133.

Boiler pressure, ...	148 lbs.
Cut-off, ...	10 in.
Throttle open, ...	$\frac{1}{3}$
Speed, ...	48.6 m.
Av. cyl. press., ...	39.4 lbs.
Ind. H. P., ...	584
Grade, ...	level.
Loss init. press., ...	44 lbs.

595. By the use of smaller drivers, both the cylinder and boiler power are in effect increased proportionately, so far as tractive power in pounds is concerned, at the expense of speed; so we may conclude, as we began (par. 483), by saying that within the limits of necessary freight speeds any tractive power is feasible which the adhesion between the drivers and rails is capable of transmitting. At passenger speeds it is quite otherwise.

596. Passenger engines, running at speed, almost never need to have their ultimate tractive power in pounds available, and accordingly we find that they

often fall in practice very far below it; nor can this be considered an evil. As a small reduction of speed means a considerable increase of tractive power, we see another reason beside the great aid given by momentum (par. 397) why the practical limit to the power of passenger engines is but little affected by the grades, within moderate limits, provided the average speed is not brought too low by the necessary reduction at a few points.

597. Tables 151 and 152 and Figs. 140 to 148 not unfairly represent the average conditions of American freight practice. The full-line diagram in Fig. 140 shows about the highest average pressure which is ever practically realized *except in starting*, and comes very near to the latter in the form of the diagram,

TABLE 151.

CYLINDER TRACTIVE POWER OF VARIOUS ENGINES FOR AN AVERAGE EFFECTIVE PRESSURE OF 100 LBS. PER SQUARE INCH.

Formula: $T = \dfrac{\text{diam.}^2 \text{ cylinders} \times \text{stroke}}{\text{diam. drivers}} \times \text{mean effective pressure.}$

SIZE OF DRIVERS. INCHES.	• SIZE OF CYLINDERS.				
	16 × 24	17 × 24	18 × 24	19 × 24	20 × 24
48........	12,800	14,450	16,200	18,050	20,000
50........	12,288	13.872	15,553	17,328	19.200
52........	11,815	13,339	14.954	16.662	18,468
54........	11.378	12.844	14.400	16,044	17.778
56........	10.971	12.386	13.886	15.474	17.143
58........	10.593	12,237	13.407	14.938	16,552
60........	10.240	11.560	12,960	14.440	16,000
62........	9.910	11,187	12,542	13.974	15.484
64........	9.600	10,838	12,150	13,538	15,000
66........	9.309	10,509	11,782	13,128	14.546
68	9.035	10.200	11,435	12.749	14,118
70........	8,778	9.909	11,109	12,377	13.714
72........	8,533	9,633	10,800	12,033	13,333

FOR A DIFFERENT STROKE.—For a stroke of 22 instead of 24 in., diminish the tabular tractive force for given diameter of cylinder and drivers by $\frac{1}{12}$, or multiply by $\frac{11}{12}$ ($\frac{22}{24}$).

For a 26 in. stroke, increase the tabular quantity by $\frac{1}{12}$.
" 28 " " " " " " " $\frac{1}{6}$.
" 30 " " " " " " " $\frac{1}{4}$, etc.

FOR A DIFFERENT SIZE OF DRIVERS.—The tractive force is inversely as the diameter of the drivers, whence it may usually be determined from the above table by a simple proportion, or computed directly, as also for a different diameter of cylinder.

One hundred pounds average pressure is as high as can be *counted on*, even in starting from 130 to 140 lbs. boiler pressure.

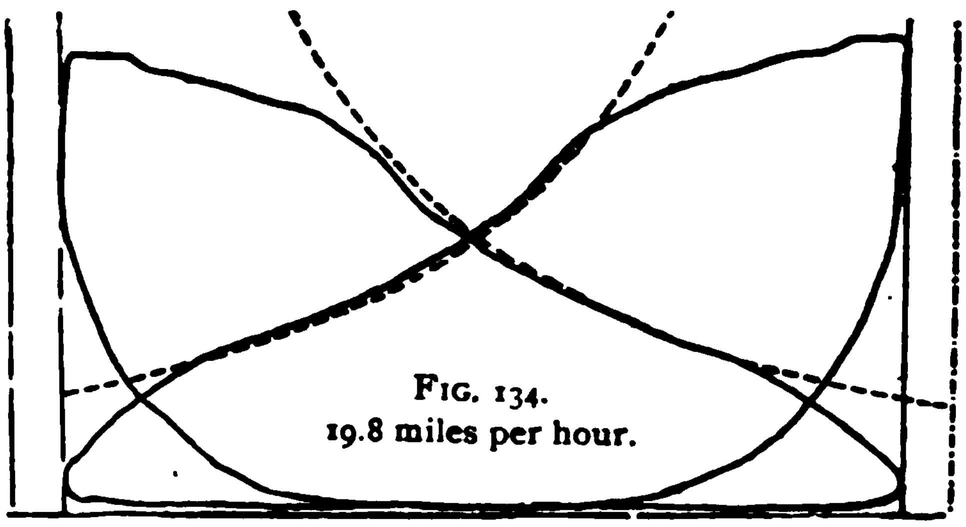

FIG. 134.
19.8 miles per hour.

	Lbs. per sq. in.
Boiler Pr.	129.
Initial "	112.5
Back "	2.0
Mean "	55.4

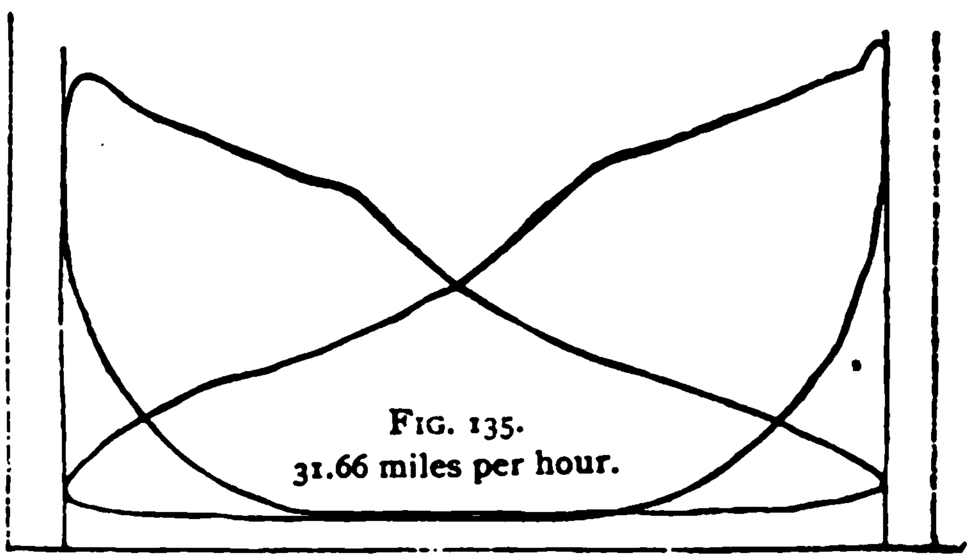

FIG. 135.
31.66 miles per hour.

	Lbs. per sq. in.
Boiler Pr.	135.
Initial "	122.0
Back "	9.6
Mean "	48.9

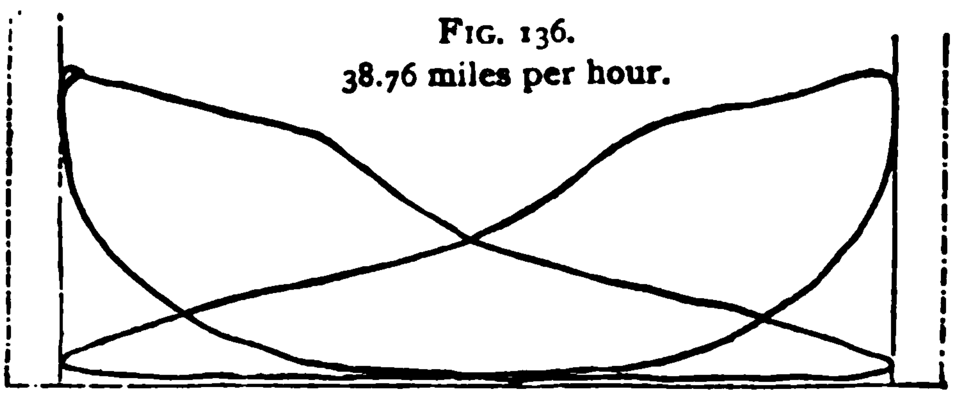

FIG. 136.
38.76 miles per hour.

	Lbs. per sq. in.
Boiler Pr.	98.
Initial "	78.6
Back "	2.8
Mean "	33.2

All three of the above diagrams have the same cut-off, ⅛. Had the full boiler pressure been as effective as initial pressure in each diagram, we should have had—

	FIG. 134.	FIG. 135.	FIG. 136.
Speed	19.8 M.	31.66 M	38.76 M.
Theoretical mean pressure	93.66 lbs.	98.01 lbs.	71.15 lbs.
Actual " "	55.4	48.9	33.2
Loss of pressure	38.3	39.1	38.0

but there would not ordinarily be quite so great a falling off in initial pressure, although Fig. 144 shows a still greater one; the main loss in both cases being due to cylinder condensation. As this is nearly constant *per hour*, it becomes a very serious matter unless steam is rapidly passing through the cylinders. It will

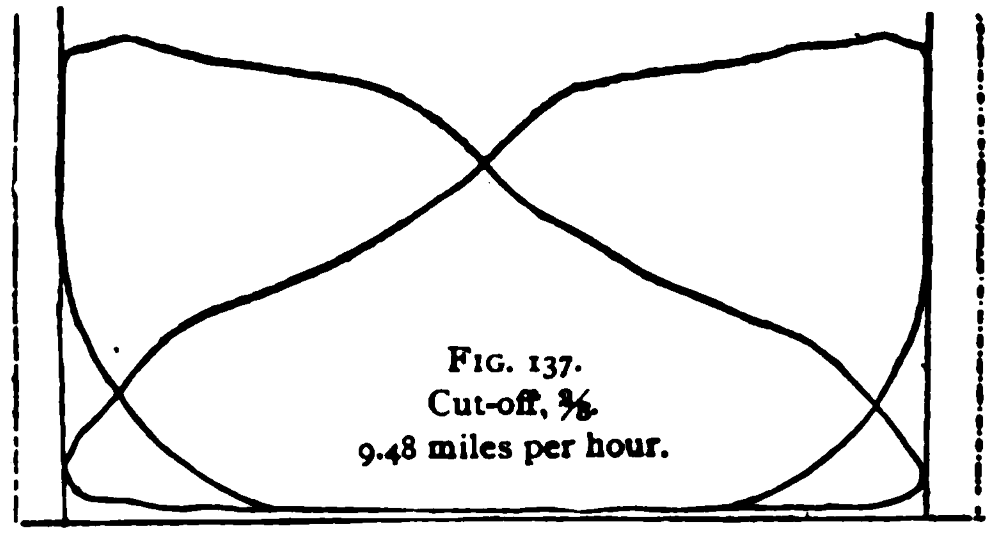

FIG. 137.
Cut-off, 5/8.
9.48 miles per hour.

	Lbs. per sq. in.
Boiler Pr.	140.
Initial "	135.8
Back "	1.0
Mean "	111.7

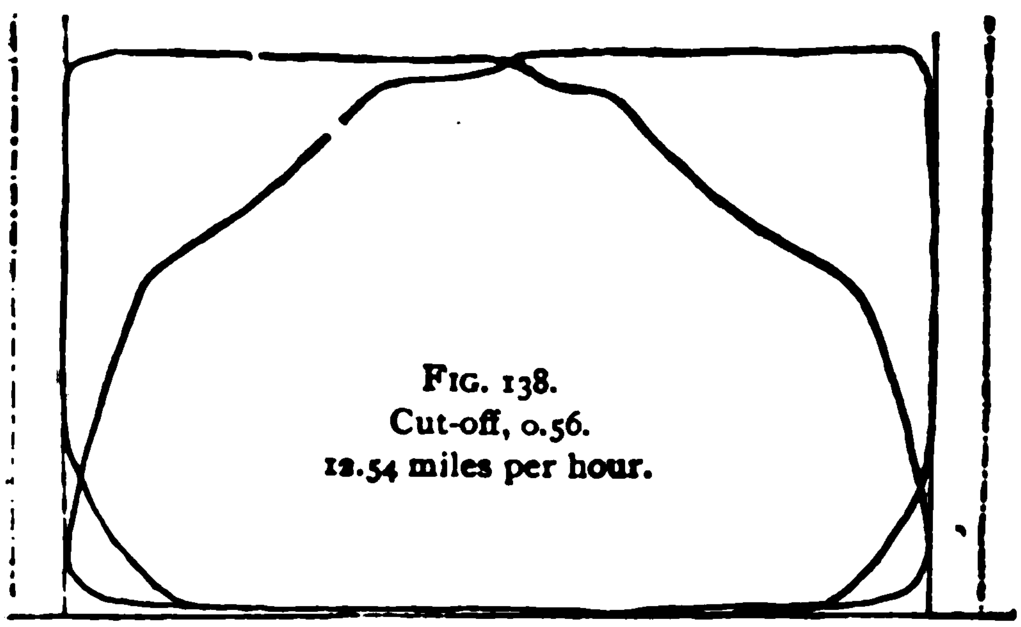

FIG. 138.
Cut-off, 0.56.
12.54 miles per hour.

	Lbs. per sq. in.
Boiler Pr.	130.
Initial "	123.8
Back "	2.1
Mean "	90.6

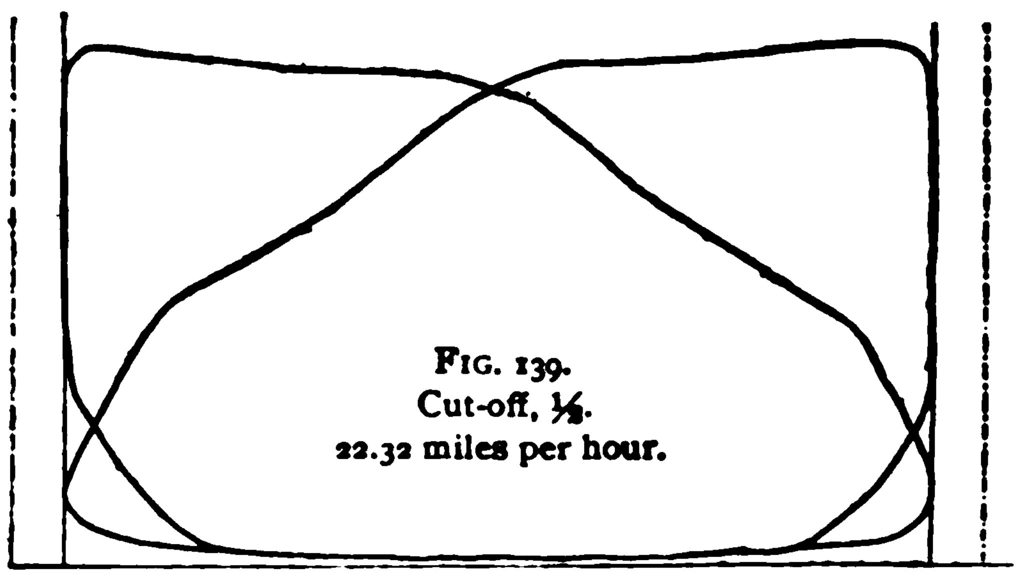

FIG. 139.
Cut-off, 1/3.
22.32 miles per hour.

	Lbs. per sq. in.
Boiler Pr.	132.
Initial "	115.
Back "	1.9
Mean "	72.2

Figs. 134 to 139, diagrams of 16 × 24 American Engine, 61-in. drivers, taken on the test trip of which details are given in Table 146–7.

be seen that only 71 per cent of the boiler pressure is realized in the cylinders, and that even then it is developing a fairly high average horse-power. Both Figs. 140 and 141 develop the effect of higher speed to reduce tractive force very clearly, and also show, by the comparative indicated horse-power, that it

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TABLE 152.

INDICATOR TESTS OF MOGUL ENGINE, 18 × 24, CINCINNATI, NEW ORLEANS & TEXAS PACIFIC RAILWAY, HAULING TRAIN OF 11 LOADED AND 23 EMPTY CARS, 836,000 LBS.

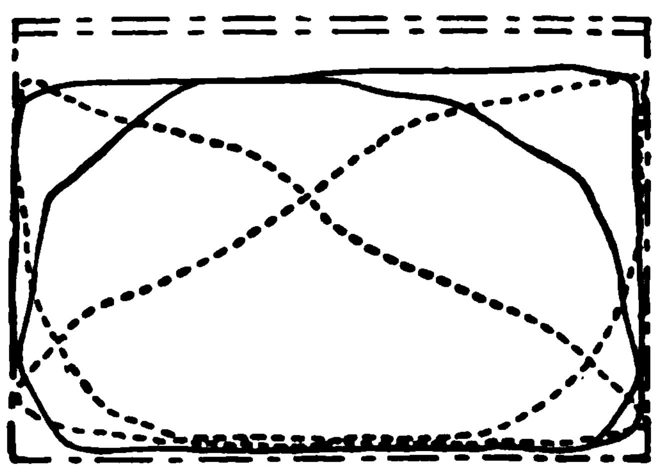


FIG. 140.

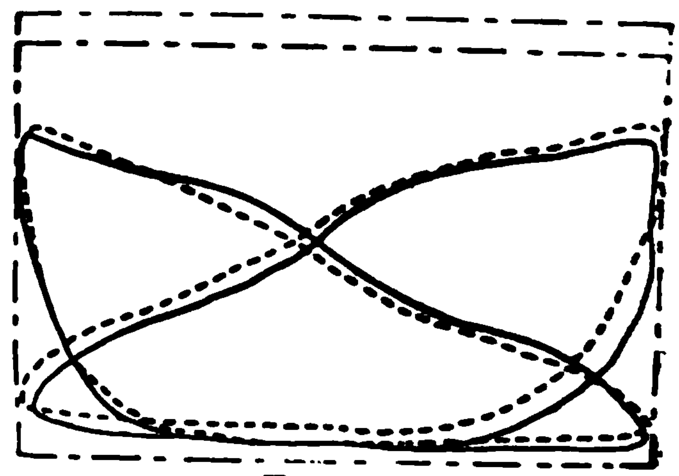


FIG. 141.

	——— (Fig. 140)	.... (Fig. 140)	——— (Fig. 141)	.... (Fig. 141)
Boiler pressure	140 lbs.	135 lbs.	130 lbs.	140 lbs.
Cut-off........	14 in.	10 in.	10 in.	16 in.
Throttle open..	Full.	Full.	½	⅝
Speed per hour	9.4 m.	20.0 m.	24.3 m.	29.3 m.
Av. cyl. pres..	99.6 lbs.	62.4 lbs.	52.0 lbs.	48.8 lbs.
Ind. H. P.....	443	593	602	680
Loss init. pres.	21 lbs.	15 lbs.	28 lbs.	34 lbs.

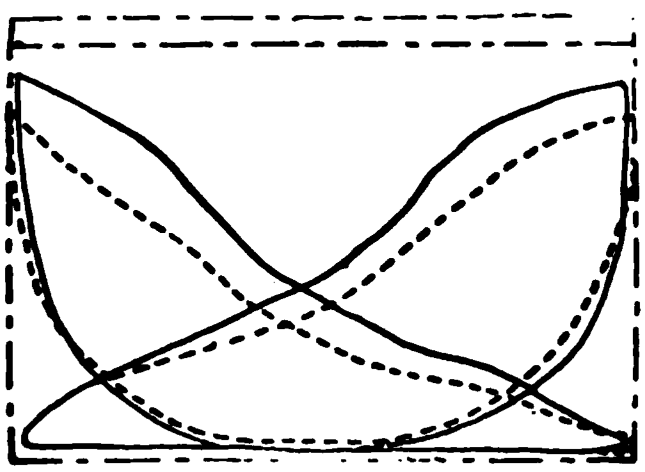


FIG. 142.

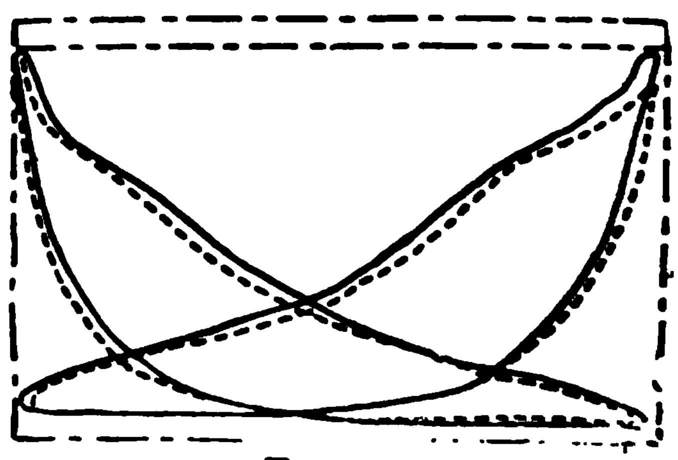


FIG. 143.

	——— (Fig. 142)	.... (Fig. 142)	——— (Fig. 143)	.... (Fig. 143)
Boiler pressure	140 lbs.	132 lbs.	135 lbs.	127 lbs.
Cut-off........	7 in.	7 in.	7 in.	7 in.
Throttle open..	½	½	Full.	½
Speed per hour	12.5 m.	27.3 m.	35.9 m.	31.2 m.
Av. cyl. pres ..	47.0 lbs.	37.7 lbs.	32.7 lbs.	30.6 lbs.
Ind. H. P.....	279	491	558	455
Loss init. pres.	17 lbs.	20 lbs.	9 lbs.	12 lbs.

TABLE 153.

INDICATOR TESTS OF MOGUL ENGINE, 19 × 24, CINCINNATI, NEW ORLEANS & TEXAS PACIFIC RAILWAY, HAULING A HEAVY FREIGHT TRAIN, 28 CARS, WEIGHING, WITH LOAD, 969,000 LBS. AVERAGE SPEED OF ALL TESTS, 26.4 MILES PER HOUR. AVERAGE I. H. P. 426.

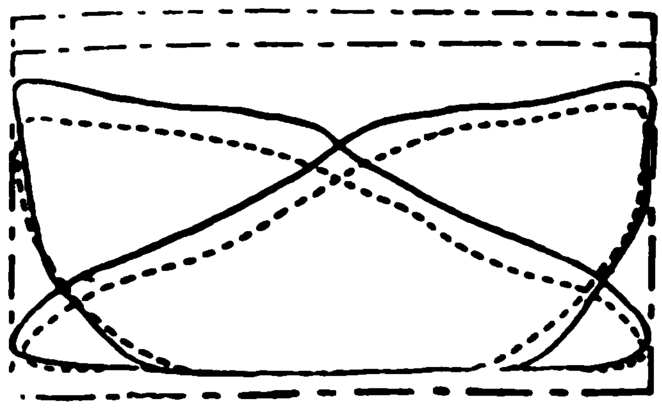


FIG. 144.

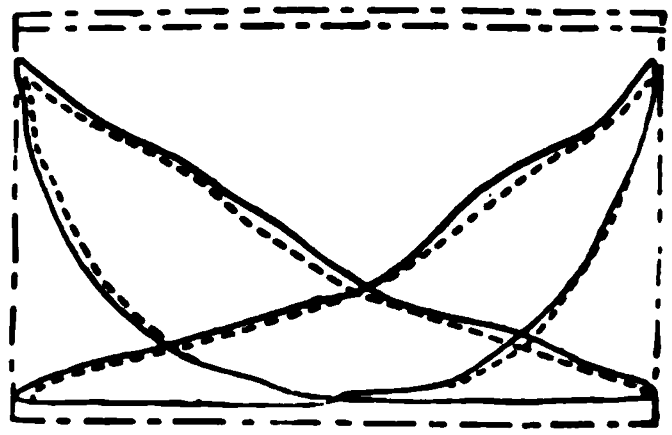


FIG. 145.

	———	············	———	············
Boiler pressure	110 lbs.	120 lbs.	125 lbs.	132 lbs.
Cut-off........	12½ in.	12½ in.	7 in.	7 in.
Throttle open..	¾	⅝	½	⅝
Speed per hour	18.7 m.	20.9 m.	29.4 m.	27.5 m.
Av. cyl. pres..	55.7 lbs.	47.9 lbs.	30.6 lbs.	29.0 lbs.
Ind. H. P.....	460	440	396	351
Loss init. pres.	10 lbs.	29 lbs.	9 lbs.	20 lbs.

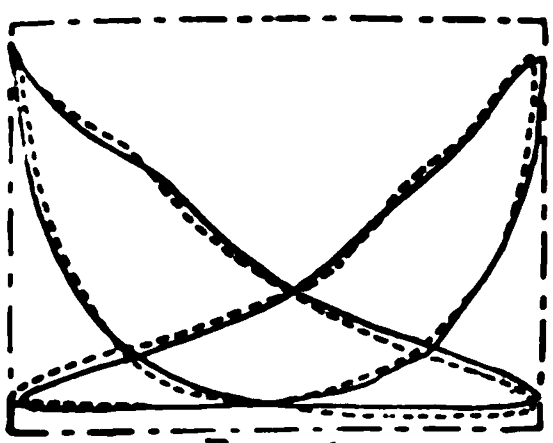


FIG. 146.

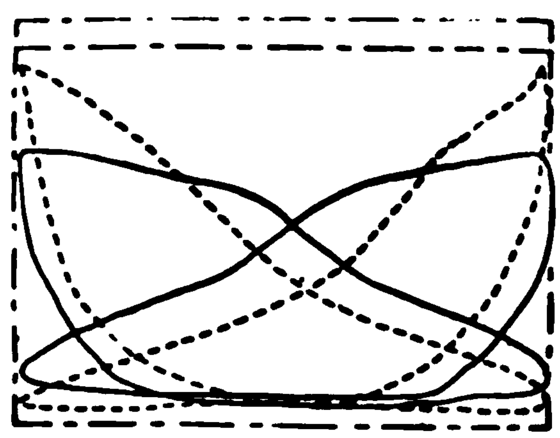


FIG. 147.

	———	············	———	············
Boiler pressure	130 lbs.	130 lbs.	120 lbs.	130 lbs.
Cut-off.......	7 in.	7 in.	12½ in.	12½ in.
Throttle open..	⅞	½	⅞	½
Speed per hour	32.2 m.	30.6 m.	21.9 m.	30.6 m.
Av. cyl. pres..	31.8 lbs.	32.1 lbs.	43.8 lbs.	33.9 lbs.
Ind. H. P.....	450	432	422	456
Loss init. pres.	8 lbs.	10 lbs.	33 lbs.	14 lbs.

can do no possible harm, so far as the load hauled is concerned. Figs. 142 and 143 develop the same facts still more forcibly. Seven of the eight diagrams of Table 152, it will be seen, develop nearly the same horse-power, 600 being about the maximum for this type of engine, and amounting to 35 horse-power per square foot of grate per hour—which is more than can be averaged, but is often reached for the moment (see par. 550).

598. Table 153 shows the performance of a somewhat heavier engine hauling a heavier train, but doing less work. Very naturally, the effect of speed to modify the average cylinder pressure is less conspicuous. In the two diagrams given in Fig. 147 we see the effect of speed to reduce the effective pressure very clearly, for Fig. 146 and others show that throttling alone accounts for but a small part of the difference.

599. Fig. 148 shows a couple of diagrams taken from a test of a Consolidation engine on the same road when doing fairly heavy work, about 20 H. P. per square foot of grate per hour, or about 80 per cent of an everyday maximum. The way in which the same horse-power is produced and used up in a very different way is very clearly brought out.

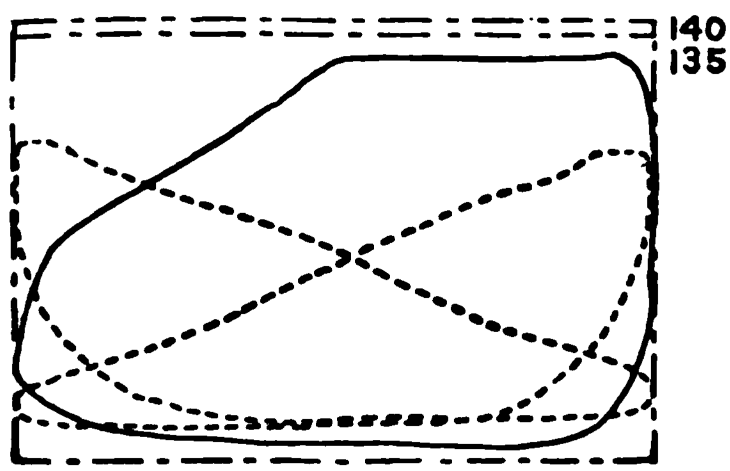


FIG. 148.

Boil. Pressure. Lbs.	Cut-off. Ins.	Throttle.	Speed. Miles per Hour.	Av. Cyl. Pressure. Lbs.	Indicated H. P.	Loss without Pres. Lbs.
140.	15.	7/8	12.4	93.3	605	11.
...... 135.	13.	1/2	29.1	40.5	616	35.

CHAPTER XII.

ROLLING-STOCK.

600. ONE of the greatest changes in the recent history of American railways, and one which has contributed as powerfully as any to the great reduction in cost of transportation which has taken place, is the marked increase in the average capacity of freight cars—an increase which has been accompanied by a very slight increase in the dead weight of the cars. In Table 154 are given the leading dimensions of both the new and old standard freight cars of the Pennsylvania Railroad, which may be accepted as in a measure typical of all American rolling-stock, and the contrast is at once evident.

This change has taken place almost entirely since the first edition of this treatise was prepared, in 1876, and is in good part the result (and the most useful result) of the narrow-gauge movement, which concentrated attention upon admitted extravagances of past administration. In part it is an indirect effect of the introduction of steel rails. A still more potent cause, however, has probably been the enormous increase in volume of traffic, especially in bulky freight to be transmitted great distances at low rates, which made the last degree of economy indispensable.

601. Ten or twelve years ago, ten tons (20,000 lbs.) was the ordinary maximum load for freight cars, 24,000 lbs. only occasional, and 30,000 lbs. almost unheard of; but of the capacities now specified (1885), 40,000 lbs. is more common than any other, anything less than 28,000 or 30,000 quite exceptional, and 50,000 lbs. no longer rare. There were in 1885, 180 flat cars and 10 box cars of 60,000 lbs. capacity on the Northern Pacific, and from 2 to 10 of the same capacity on a number of other roads. Of 50,000-lb. or 25-ton cars there are far more, numbering several thousands on many roads, and this bids fair to become the standard coal car; while there are not a few box cars in use of that capacity. As fair evidence as any, perhaps, of the great increase in the average car-load in recent years is the classification list of the Pennsylvania Company, given in Table 155, which includes all the freight rolling-stock of that company's system, existing in sufficient numbers to form a class, in 1885.

TABLE 154.

LEADING DIMENSIONS OF VARIOUS OLD AND NEW STANDARD FREIGHT CARS OF THE PENNSYLVANIA RAILROAD.

KIND OF CAR.	LENGTH.		WIDTH.		HEIGHT.		Weight. Lbs.	Capacity. Lbs.
	Body.	Out. to Out.	Body.	Maximum.	Body.	Maximum.		
Box—Old standard	28' 4¼"	31' 0¾"	8' 7¾"	8' 11¼"	10' 4½"	11' 10⅝"	20,900	30,000
New standard	34' 8¼"	37' 6"	9' 0¼"	9' 6"	12'	12' 9⅞"	24,800	50,000
Stock—Old standard	28' 0"	31' 0¾"	9' 0"	9' 6"	10' 7⅜"	11' 11⅛"	21,000	22,400
New standard	34' 6½"	37' 6"	9' 0"	9' 6"	12'	12' 9⅞"	26,200	35,000
Gondola or Flat	31' 1½"	34' 3"	8' 6"	8' 7½"	1' 6"	8' 5"	17,280	30,000
Hopper—Old standard	33' 7½"	36' 9"	8' 0"	8' 0"	6' 6½"	7' 1"	22,200	40,000
New standard	24' 0"	27' 2"	8' 0"	8' 6"	8' 1"	8' 6"	19,800	50,000
Four-wheel	11' 0"	13' 6"	6' 6¾"	6' 6¾"	7' 0"	7' 7"	7,750	13,000
Caboose—Four-wheel	15' 1¾"	20' 4"	8' 5½"	9' 1½"	10' 7"	13' 8"	16,000	....

THE TRUCKS have axles 4 ft. 10 in. apart and weigh 4500 lbs. Axles 5 ft. apart are now becoming standard. All the Pennsylvania cars have an END PLATFORM about 10 in. wide outside the body of the car proper, increasing by so much the length of the floor and car for the same floor space. Some 20 or 25 per cent only of the cars in the United States have these platforms, and while having certain advantages they are not generally approved.

The West Shore standard box car is almost precisely similar to the new standard above in extreme dimensions, weight, and capacity, but has no end platform, the body being so much longer. It may be considered typical of the modern tendency.

THE STANDARD CAR WHEEL on this and all other lines in the United States (except the Baltimore & Ohio and a few minor lines, which use 30 in.) is 33 in. in diameter, and weighs from 510 to 575 lbs., averaging about 525 lbs. The M. C. B. standard axle weighs 347 lbs. A new axle about 25 lbs. heavier has recently been adopted.

Table 155 is interesting, not only as giving the average capacity, but for the variety of dimensions appearing among the standard types of a single line. It will be seen that in these 13 classes there are 10 different lengths (not counting differences of less than an inch), and 9 different widths, ranging by jumps of a few inches each from 7 ft. 5 in. to 8 ft. 11 in.; all in freight service only. This diversity is in part because the cars must be adapted to many different uses, but in the main it is evidence of the fact that a process of evolution is still going on, so that the rolling-stock of the country is for the present in a transition state. The general tendency of this process can alone be stated: to increase the capacity of freight cars up to 25 or even 30 tons of paying load, and perfect their construction so that such loads may be handled with safety, at fairly high speeds.

602. Two changes which may reasonably be expected to come about in the next few years will greatly strengthen this tendency, and probably materially modify the handling of freight trains as well—the

TABLE 155.

CLASSIFICATION LIST OF FREIGHT CARS OF THE PENNSYLVANIA COMPANY, 1885.

KIND OF CAR.	Class.	INSIDE DIMENSIONS. Length.	Width.	Height.	Standard Capacity.
		ft. in.	ft. in.	ft. in.	lbs.
Long box*	Q.	33 10¼	8 4¼	7 4	40,000, 50,000
Box*	M.	27 5¼	7 11¼	5 10¼	26, 30, 40,000
Refrigerator	R.	27 4¼	7 10⅛	5 8⅛	40,000
"	M. & O.	21 5	7 10	5 10	40,000
Provision	M. & O.	23 1	7 10	5 10	40,000
Stock (standard)	O.	33 10	8 5	7 2	40,000
" "	P. B.	29 4¾	8 3	6 9	26, 28, 30,000
Gondola (standard)	P. D.	29 8¾	8 0	2 6	26, 30, 40,000
" (widened)	P. E.	29 8¾	8 4	2 6	50,000, 60,000
" (standard, long)	E.	33 0	7 5	2 6	40,000
Drop bottom (standard)*	D.	33 0	7 5	2 6	40,000
Hopper bottom (standard)*	C.	23 5	7 7	3 11	50,000
Stone flat (standard)	S.	35 7	8 11	....	50,000

Standard height of floor from rail, all cars, 4.0¼. P. D. gondolas, built before present standards were adopted, have sides only 20 in. and 2 ft. high.

The weights of these cars are substantially the same as those for the Pennsylvania Railroad, given in the preceding table, those marked * being substantially, if not exactly, the same cars.

adoption of some form of automatic coupler, and the adoption of a freight-train brake. The effect of all these causes combined will probably be to assimilate the handling of freight trains more and more to the handling of passenger trains, except that the speed will be much more variable: as low as now on heavy grades, but very much higher on the easier sections of the line, where great tractive force is not demanded, and where, consequently, higher speed is entirely feasible. As the ordinary passenger piston speed is not found to be injurious, we may expect with some confidence that at no distant day maximum freight speeds of 28 to 30 miles per hour, which would give about the same piston speed, will be established in general practice.

The effect of this change will be to greatly facilitate the hauling of heavy trains, even without considerable modification of gradients, for reasons discussed in Chapter IX., and elsewhere. With the more perfect road-beds and track which become every year more general there is no reason to believe that wear and tear will be materially increased, while the cost of power per ton-mile will certainly be rather less than more, not only because of the less time afforded for radiation of heat from the exterior of the locomotive and journal-boxes and interior of the cylinders, but from less destruction of energy by brakes, since it can be stored in the train in the form of velocity, and afterwards used, to a much greater extent.

603. The primary requirement for the attainment of this desirable end is the adoption of a freight-train brake, and fortunately there now appears every prospect that some approved form of freight-train brake will come into general use within a few years, and thus greatly simplify the problem of obtaining the most favorable virtual gradients cheaply, in addition to the direct advantages. The latter alone are much considered by the public, but on certain lines at least their effect on the virtual gradients will almost certainly be of more financial importance, and make the expenditure for train-brakes a most profitable one, independently of the greater safety and convenience.

604. The ultimate solution of the problem of automatic couplers is a more doubtful matter, and it may be well on toward the close of this century before automatic couplers come into use. To the highest efficiency of train-brakes they are almost essential, and the breaking in two of trains is another evil, tending to discourage the hauling of heavy trains, which they will very largely remedy. The chief obstacle to their introduction is and has always been, not the mechanical difficulty of the problem, but the fact that, owing to the continuous interchange of cars, no real benefit would be derived from such a coupler until it had come into almost universal use, whereas a passenger-coupler was as useful to the road applying it as it ever could be, as soon as it was applied

to their own cars, or even to a few trains. The consequence of this difference is that the usual cut-and-try process of development and survival of the fittest was impossible with freight couplers, whereas the first practicable passenger-coupler was adopted by a few roads almost immediately, from which the contagion of example sped, each gaining the full benefit of their own expenditure as soon as made, and losing nothing by the backwardness of others.

The greatest immediate obstacle to a general agreement on some one freight-coupler, or on two or more couplers working well together, is the existence of two distinct types of such couplers, which have become known as the "link" and (by a somewhat awkward and inappropriate term) "vertical-plane" or lateral-hook couplers. The link type resembles more or less closely the ordinary form of coupler, but arranged to work automatically, and, in the best types, dispensing with loose links and pins. The hook type is modelled after the couplers which have been so successful in passenger service. Fig. 149 shows one of the most approved forms of link-couplers—the Ames, and Figs. 150, 151 one of the most approved forms of hook-couplers—the Janney. Neither of these couplers has been selected for illustration as the best of its type, but merely as fairly representative and among the best and most approved.

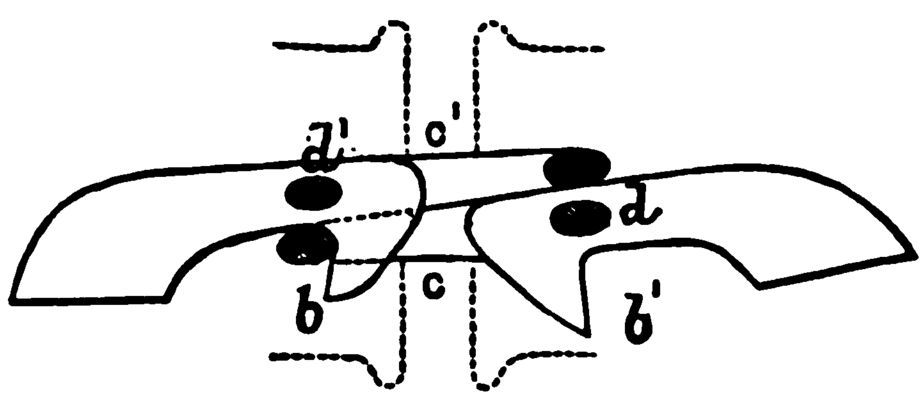


FIG. 149.—AMES (LINK) CAR-COUPLER.

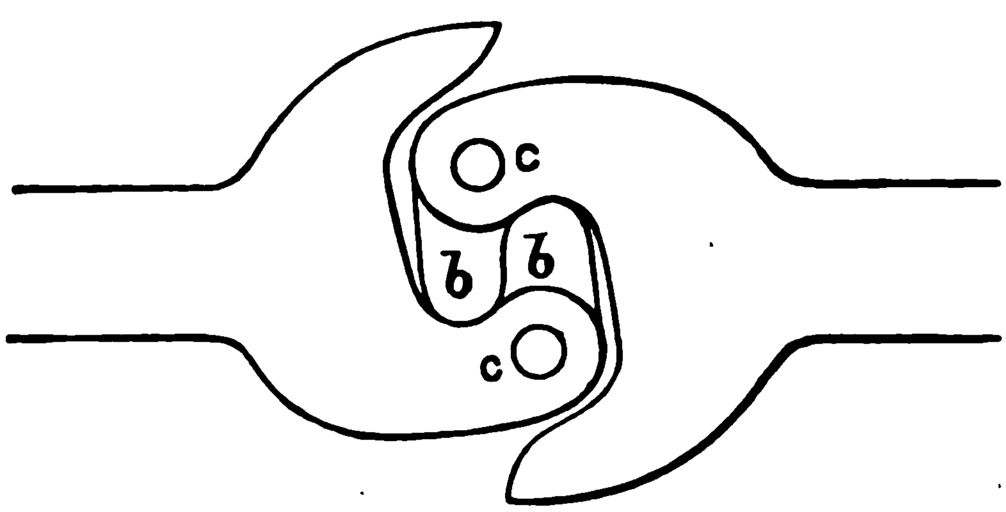


FIG. 150.

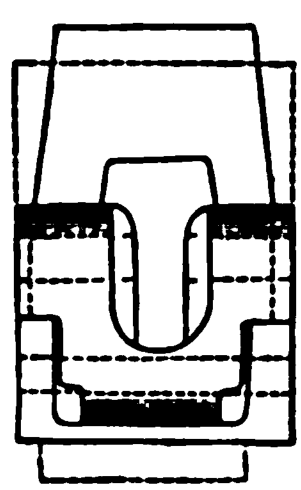


FIG. 151.

JANNEY (HOOK) CAR-COUPLER.

605. Each of these types has strong advocates, but it may be expected with some confidence that the hook type will ultimately, and perhaps very speedily, prevail, for the reason that it insures a steadier and smoother motion of the train by doing away with loose slack, which is the chief provocative of breaking in two of trains and of broken draw-bars and other damage, while it has been proved not to be of appreciable advantage in starting heavy trains. There is

a general impression to the contrary, and not a little floating evidence; but in careful tests at Burlington, Ia., 1886, it was found that there was nothing gained by loose slack more than could be secured by first backing the locomotive against brakes set at the rear of the train, and so compressing the springs throughout the train. On the locomotive starting forward the compressed springs give a push to each car, and this push seems to be more effective than when the same thing is done with a train having slack.

As several good couplers of each type now exist which will work quite well together, nothing now impedes a decision of the coupler question except the existence of these two types, each of which has certain advantages. The advocates, of each are indisposed to proceed very actively with the equipment of their cars until the vexed question of a choice is settled.

606. In Table 156 are given various details as to certain very large or heavy freight cars, and in Table 157 the leading dimensions of the more usual passenger cars. In respect to the latter, the tendency is more and more toward the use of the heavy sleeping and drawing-room cars for a large percentage of

TABLE 156.

DIMENSIONS OF CERTAIN VERY LARGE AND HEAVY FREIGHT-CARS.

	Furniture Car Chicago & N. W. Railway.	M. C. B. Standard 60,000-lb. Box Car.	Pile-driver Car Ga. Central Railroad.†	Philadelphia & Reading Standard Coal Car.
	ft. in.	ft. in.	ft. in.	ft. in.
Length over sills	38 0	35 0	44 0	24 0
Width over sills	8 6	9 0	10 0	7 6
Length over roof	38 7½	34 0	....	22 0
Width over roof	9 1½	9 0	....	7 6
Inside length	37 6¼	....	....	....
" width	8 0¼	....	....	....
" height	8 5⅝	....	....	....
Extreme height	13 8¼	11 10*	....	7 11
" length	40 11½	31 6	....	24 6
Total wheel-base	31 10⅝	....	....	....
Weight	....	....	32,000 lbs. +39,000 "	18,480 lbs.
Capacity	40,000 lbs.	60,000 lbs.	....	56,000 "

* To top of brake-shaft, 12 ft. 10 in.

† Leaders to hammer, 40 ft. high, taking a pile 18 in. × 50 ft.; 58,000 lbs. on one truck when moved back to let the front of the car project. Four trucks in all. Hammer, 8000 lbs.

the travel, and many through-trains consist of them almost exclusively—a fact which tends to make the rate of long grades and of grades at stations of almost as much importance to them as to freight trains, but owing to the fact that, by varying high velocities slightly, a great difference in tractive power on up grades results, and all but quite long grades may be operated almost as virtual levels (par. 397), the disadvantage of dead weight is VERY MUCH less in passenger service than is sometimes assumed, and the tendency toward luxury in that respect may be expected to continue.

Drawings and dimensions of a great variety of cars, and of all car details, will be found in the CAR-BUILDERS' DICTIONARY, as revised by the writer.

TABLE 157.

LEADING DIMENSIONS AND WEIGHT OF SUNDRY PASSENGER CARS.

PENNA. RAILROAD. STANDARDS.	LENGTH.		WIDTH.		Height.	Weight	Capacity.	Weight One Truck.
	Body.	Out to Out.	Body.	Max.				
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	lbs.	Pass.	lbs.
Passenger*	†46 6	52 9	9 10	10 1¾	14 1⅝	*44,989	51	7,200
Baggage	40 0	46 0	9 10¼	10 1¾	14 1⅝	32,000	....	....
Postal	‡60 9¼	66 11¾	9 10¼	10 1¾	14 1⅛	58,000	20,000 lbs.	....
Sleeper (old style)	§58 0	64 8	10 0	10 1	13 10	....	...	....
Dining ‖ (C., B. & Q.)	64 0	....	10 4	10 6	14 2	82,500	10 sec.	‖15,500
Monarch sleeping-cars	....	75 0	....	....	....	75,000	....	...
Mann sleeping-cars	...	....	....	....	....	71,000	....	....
Parlor Car (B.& O.R.R.)	58 0	65 0	9 6	10 0	14 0	70,000	28	16,200
Woodruff sleeper	....	71 0	....	10 3	15 5	60,000	....	....
Harl. & H. Co., 1st-class passenger	49 6	57 8	9 6	....	13 6	....	58	....

* The Lehigh Valley standard passenger car, of the same general dimensions as this, weighs 45,136 lbs.; one truck, 8624 lbs.

† Centre to centre of truck, 33 ft.; 7 ft. wheel-base.

‡ Centre to centre of truck, 46 ft. 2¾ in ; 10 ft. wheel-base.

§ Centre to centre of truck, 44 ft.; 14 ft. wheel-base.

‖ Six-wheel, 10 ft. 6 in. wheel-base.

Sleeping-cars have usually 12 sections and a state-room and smoking-room ; sometimes only 10, rarely 14; and a few cars have 16 sections, but without state-room or smoking-room. Many sleepers and parlor cars weigh 75,000 to 78,000 lbs. Pullman sleeping-cars built for English service are much narrower than in American practice, and weigh only some 48,000 lbs.

CHAPTER XIII.

TRAIN RESISTANCE.

607. ALTHOUGH over fifty years have passed since experimental investigations in respect to it began, there is no single element of train resistance whose laws can be said to be definitely known. Within the years 1875–1885, however, much progress has been made, and although our knowledge is still defective, yet the limits of error are now quite narrow.

608. Train resistance, properly so called, may be defined as the sum of all the resistances which CONSTITUTE A TAX UPON THE ADHESION of the locomotive; thus excluding all those resistances which are internal to the locomotive itself, and hence are a tax upon the cylinder power only, which is a much less serious matter. These latter resistances are (1) all the friction of the valve-gear, piston, and connecting-rods, and (2) all *journal*-friction of the driving-wheels. The resistances which do tax the adhesion are (1) the *rolling*-friction proper (between wheel and rail, Fig. 152) of the drivers, with (2) both the rolling and the journal friction of the truck-wheels, or of any other wheels not drivers; (3) all head and other atmospheric and oscillatory resistance of the locomotive; (4) all grade resistance of the locomotive and (5) all resistances, of every kind, of the train behind the locomotive.

609. Simple as would seem the problem of determining what is and what is not a tax upon the adhesion, frequent errors have arisen in determining it, both by including among the resistances which tax the adhesion the journal-friction of the drivers and even the friction of the machinery, and by excluding from it the atmospheric, oscillatory, and even grade resistance of the locomotive.

610. It seems especially plausible to assume that all resistances which would still exist if the engine were a dead engine, with disconnected side-rods, hauled by another engine in front of it, are a tax upon the adhesion when the engine is under steam. This is not correct, for it includes as a tax on the adhesion the considerable item of the journal friction of the locomotive.

The true test for what is and is not a tax upon the adhesion, is to conceive

the locomotive to be stationary and lifted from the rails with belts on the drivers. Whatever power would then be lost by friction within the locomotive itself, before it reached the belts, is similarly consumed in the locomotive without taxing the adhesion. All the remainder of the power, including any loss by the friction or wear of belt or driver, would be transmissible only by the adhesion of the belt to the driver, and the measure of that adhesion would be the measure of the net power of the engine aside from its own internal friction.

The locomotive engine, in fact, is to all intents and purposes a mechanical equivalent for a stationary engine with fly-wheel and belt, the rail being the belt. Only, instead of the engine being stationary and the belt moving, the belt is stationary and the engine moves along it. The locomotive, it is true, uses a large part of its power in raising and lowering itself on grades, but a stationary engine might easily be made to do the same without altering any of its essential features.

611. Regarding train resistance, therefore, as the sum of all those resistances which tax the adhesion, they may be subdivided as follows:

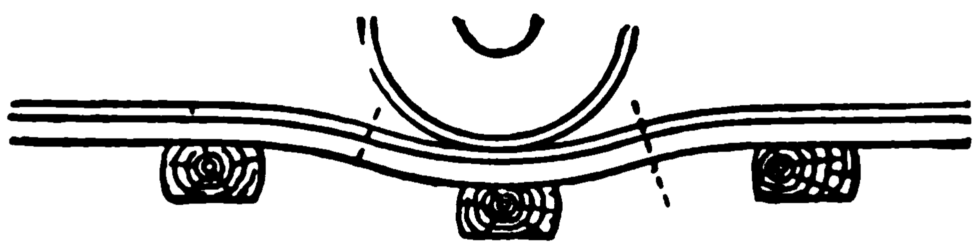


FIG. 152.

1. *The journal-friction*, between journal and bearing.

2. *The rolling-friction proper*, between wheel and rail, from the cause outlined in Fig. 152.

Both these together are commonly included, both in this volume and elsewhere, under the general name of ROLLING-FRICTION, and their aggregate only has been determined with approximate exactness. Experiment indicates that their aggregate varies somewhat, but not materially, with the velocity.

612. The three following are known collectively as the "velocity resistances;" and experiment, so far as it goes (which is not far), seems to agree with the requirements of theory, that they should vary as the *square* of the velocity:

3. *Atmospheric head and tail resistance*, including the head resistance of the locomotive and of the front car above the tender, and that resulting from the suction of the last car.

4. *Atmospheric side resistance*, including that between the successive cars.

5. Additional rolling and journal friction resulting from *oscillation and concussion*.

As with the rolling-friction, the aggregate of these three items, and especially of the last two, is far better known than the separate impor-

tance of each. The doubt on this subject goes so far, indeed, that some modern formulæ of reputation (e.g., the two compared with the author's in Table 166) assume the velocity resistance to be all atmospheric, while others assume it to be all oscillatory.

613. An additional velocity resistance, but one not commonly so called, and too easily forgotten to be an element of train resistance at all, although an essential and important element thereof, is—

6. *Stopping and starting resistance.* The nature of the large addition which it makes to the permanent train resistance has been considered in par. 368 *et seq.*

Finally we have, as the only known and invariable element of train resistance—

7. *Grade resistance*, which is sensibly the same rate per cent of the total weight of the train as the rate per cent of the grade; i.e., 20 lbs. per ton of 2000 lbs. for each 1 per cent of grade (par. 382).

On badly located lines only we need also to consider—

8. *Curve resistance.* On any well-located line its amount is considered only for the purpose of making such reduction of grade as shall eliminate it altogether. Therefore, after once completing such a line it does not constitute an element of train resistance which affects the movement of trains.

614. Another element of train resistance, in a certain sense, is *brake-friction.* While it will be most appropriately considered in this chapter, as relating to its general subject, it can only in a very figurative sense be said to be an element of train resistance, properly so called. The simplest method of computing the efficiency of brakes is given beneath Table 118, page 336, and Fig. 153 outlines the principle of the method there given. It need only be added that the average retarding efficiency of brakes may be now (1886) considered as from 10 to 14 per cent *of the load on the braked wheels* in passenger service, with air-brakes, and from 2½ to 5 per cent with hand and driver brakes on heavy freight trains. The safe pressure on the brake-shoes is not much over two thirds of the load on the wheels. The maximum retardation which has ever been realized was with an ingenious apparatus devised by Mr. George Westinghouse, by which the pressure was very great at high speeds and

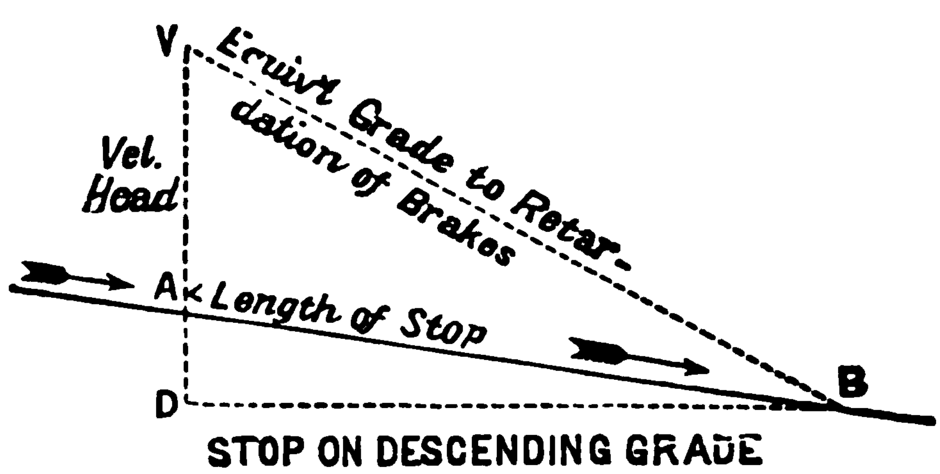


FIG. 153.

TABLE 158.

MAXIMUM EFFICIENCY OF POWER BRAKES DURING ALL PARTS OF STOPS IN PASSENGER SERVICE OR WITH SHORT FREIGHT TRAINS.

[Abstracted from computations by the writer, being averages of a large number of stops.]

Portions of Stops.	Average Speed, Miles Per Hour.	Ratios of Brake Retardation to Load on Braked Wheels.			Ratios of Brake Retardation to Pressure on Brake-blocks.	
		Westinghouse Brake.		Smith Vacuum Brake.	Galton. Theoretical (Table 112) Uniform Pressure.	
		Regular Stop.	Against Engine.		After 10 Sections.	Initial.
Last *fraction* of 100 ft	8 to 10	20.9	19.3	19.3	24.0	25.0
Last *even* 100 ft..............	20	13.9	12.9	11.6	13.3	18.2
Preceding 100 ft.	28	14.7	14.5	11.6	11.9	17.1
" "	35	13.75	15.55 13.6	14.45 9.95	8.5	15.3
" "	40	12.9	11.95	10.75	7.7	14.4
" "	44	14.2	13.85 13.8	8.35 8.9	7.3	13.8
" "	47.5	14.8	13.3	8.4	7.0	13.0
" "	50	14.75	(11.6)	8.7	6.7	12.0
" "	52	(4.5)	(8.65)	......	6.4	11.0
Averages, excluding last fraction of 100 ft.......	20 to 52	14.15	13.68	10.00	8.6	14.35

N. B.—The "average speed" given in the first line of this table is for the period of a stop *beginning* at 15 to 20 miles per hour and ending at zero, so that it averages 8 to 10 miles per hour.

For the original records of these stops, with very valuable further data on brake efficiency and the laws of brake friction, see Dredge's "Pennsylvania Railroad" (Wiley & Sons).

From analysis of these and other data the writer concluded that the following ratios represent the *maximum* efficiency of brakes in ordinary practice, being such as is fairly attainable, and is in fact attained under favorable conditions with all in good order and with the best-known appliances:

Retardation of Brakes in per cent of Load on Braked Wheels.

With special apparatus not in practical use:

About *one fifth*, or 20 per cent at all speeds.

With efficient power brakes of ordinary type:

At speeds decreasing from 15 to 20 miles per hour, about *one fifth* or 20 per cent.

At all speeds exceeding 15 to 20 miles per hour, about *one seventh*, or 14.14 per cent.

For entire stops of long trains at high speeds, including lost time in applying full brake-power, *one eighth* to *one ninth*.

was reduced automatically as the speed fell, so as to keep the retardation just within the nearly constant force necessary to skid the wheels, which is one fourth of the insistant weight. This apparatus, moreover, was applied only to a single car, and thus did away with another serious obstacle to the efficiency of brakes—that it takes a considerable time after they are applied on the engine for them to even begin to apply on the last car. With 50-car freight trains over ten seconds is lost in this way.

With this apparatus an *average* efficiency of over 0.2 was obtained for the entire stop; but it has never been introduced into service, extreme efficiency not being the end aimed at so much as cheapness, simplicity, and certainty of action. It is possible that the near future will bring about considerable differences in the brake question, and until then it is dangerous to prophesy.

615. In the analysis of the preceding elements of train resistance, and in presenting and reconciling the inconsistencies of the experimental facts on record, a volume might easily be written, and perhaps not unprofitably; but for our immediate purpose it will suffice to dismiss at once a large fraction of such experimental facts—or what purport to be such, but are not—as for one reason or another worthless as practical guides.

616. From a practical point of view, train resistance must be considered from two aspects, viz.:

1. *As respects freight trains*, to which speed is unimportant compared with hauling the largest possible loads over the points of maximum resistance.
2. *As respects passenger trains*, to which the possibility of high speed is the more important consideration.

In each case formulæ which deal with the car resistance only, neglecting the head and rolling resistance of the engine, are comparatively valueless. What we need to know most is the sum of all the resistances which tax the adhesion. We will consider each class of train resistance separately.

FREIGHT-TRAIN RESISTANCE.

617. The best existing evidence known to the writer as to what is the absolute amount of the train resistance of *entire* American freight trains in the ordinary routine of service are the observations made at the Burlington, Ia., first (1886) series of brake tests. These tests were for the primary purpose of determining precisely how much difference there might be in the normal train resistance of the various trains, apart from the action of the brakes. They were made by the "gravity method" de-

scribed in Appendix A, the train being caused to approach the starting post at as nearly as might be 20 miles per hour, when steam was shut off and the train permitted to run over a very slight down grade till it came to a stop. It was then caused to approach a succeeding stop-post at a sharp down grade, having a slightly curved alignment, at 5 miles per hour, and permitted to acquire what velocity it would (about 35 miles per hour) for a certain distance. There was no wind; and the thermometer averaged about 80° Fahr. The results of the tests are summarized in Table 160 and Fig. 154, which may be accepted as an almost absolutely accurate record of actual resistances* over the entire range of

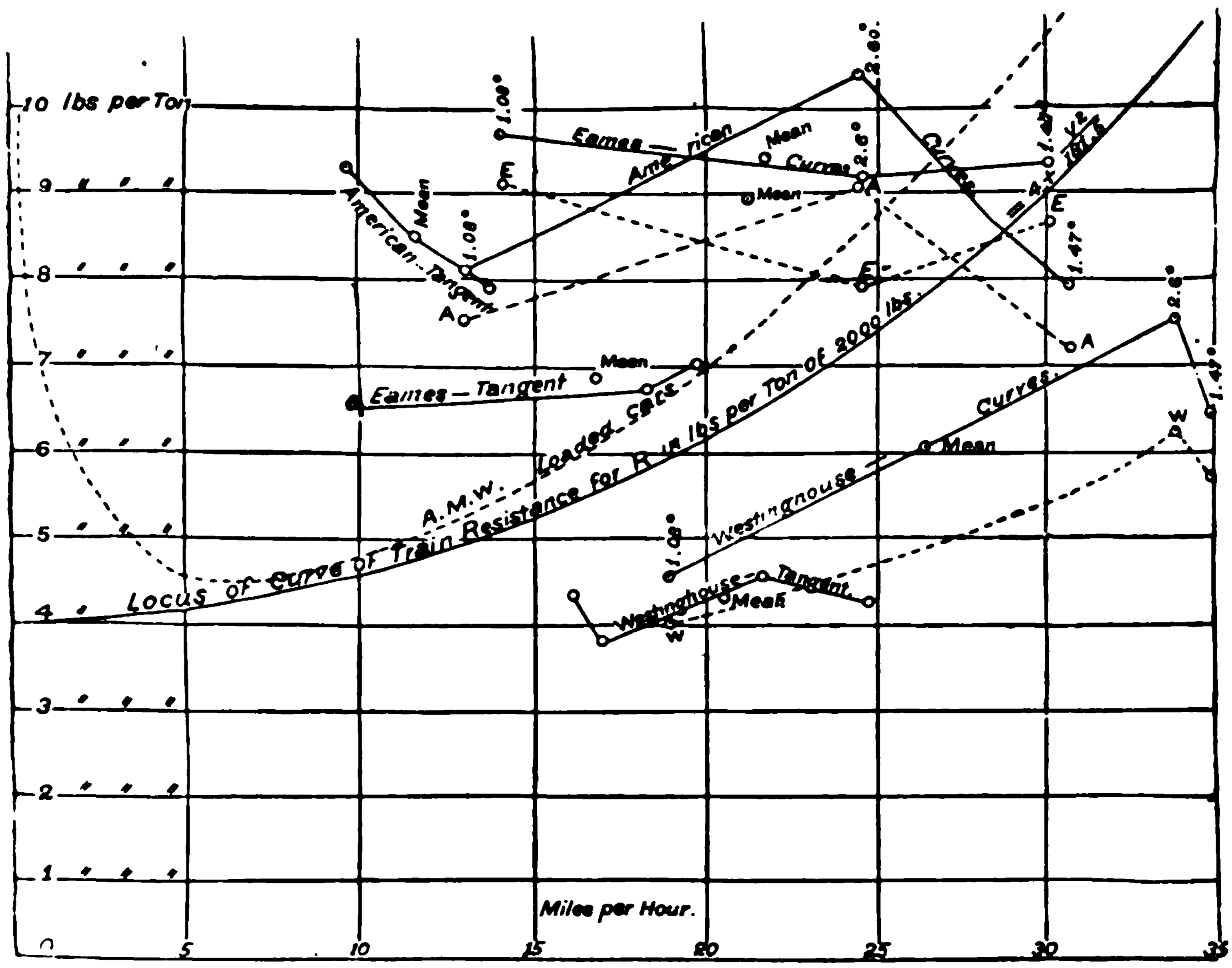


FIG. 154.—RESULTS OF THE BURLINGTON, IA., TESTS OF THE RESISTANCE OF ENTIRE TRAINS, AS SUMMARIZED IN TABLE 160, PAGE 500.

[Computed by the method shown in Table 159, on following page, and in Appendix A.]

(The dotted lines give the tests made on curved track corrected for curve resistance as per Table 160. The dotted line marked "A. M. W." is that given by the writer's formulæ, Fig. 163 and Appendix A.)

* As the writer was referee of these tests he was familiar with the condition of the cars and all other modifying circumstances. Therefore he can vouch for the accuracy of the results, which seem somewhat peculiar

TABLE 159.

MANNER OF COMPUTING GRAVITY TESTS OF TRAIN RESISTANCE OF ENTIRE FREIGHT TRAINS.

Speeds decreasing from 20 miles per hour—25 mixed-car trains, 12 loaded, 13 empty, with dynamometer car and way car—American 17 × 24 in. engines.

[Computed by the writer from test runs down a slight grade with steam shut off, at the Burlington, Ia., freight-train brake tests, July, 1886.]

(This table covers only the computation of the four lowest resistances in Fig. 154, marked "Westinghouse Tangent.")

STATION.	Elev. Track at c. g. of Train.	Speed. Miles Per Hour.	Vel.-Head (by Table 118).	Virtual Elevation.	Differences in ditto.	Pounds Per Ton Resistance.
0	724.2	21.5	16.4	740.6	....	....
1,000	723.0	21.3	16.1	739.1	1.5	....
2,000	721.3	20.6	15.1	736.4	2.7	....
3,000	720.0	21.0	15.7	735.7	1.7	....
4,000	715.8	21.0	15.7	731.5	4.2	....
5,000	710.2	23.9	20.3	730.5	1.0	....
First 5,000 feet	....	21.55	....	....	2 22	4.44
6,000	704.4	24.8	21.9	720.2	3.3	....
7,000	702.4	25.3	22.7	725.1	1.1	....
8,000	701.6	25.3	22.7	724.3	0.8	....
9,000	699.3	24.3	21.0	720.3	4.0	....
10,000	698.1	24.2	20.8	718.9	1.4	....
Second 5,000 feet	....	24.78	....	....	2.12	4.24
11,000	694.4	24.6	21.5	715.9	3.0	....
12,000	692.0	24.5	21.3	713.3	2.6	.....
13,000	694.2	21.8	16.9	711.1	2.2	....
14,000	695.0	19.8	13.9	708.9	2.2	....
15,000	697.0	17.2	10.5	707.5	1.4	....
Third 5,000 feet	....	....	....	....	2.28	4.56
16,000	698.5	14.3	7.3	705.8	1.7	....
17,000	695.9	14.6	6.6	702.5	3.3	....
18,000	693.1	16.2	9.3	702.4	0.1	....
19,000	690.3	16.7	9.9	700.2	2.2	....
20,000	684.4	18.5	12.2	696.6	3.6	....
Fourth 5,000 feet	....	....	....	....	2.18	4.36
21,000	682.2	19.0	12.9	695.1	1.5	....
22,000	684.3	16.4	9.6	693.9	1.2	....
23,000	682.5	15.4	8.4	690.9	3.0	....
3,000 feet	....	16.93	....	....	1.90	3.80
Entire 23,000 feet	....	20.51	....	....	2.16	4.32

As an illustration of the accuracy of the method, at station 9000 the resistance will be observed to be abnormally large. The same peculiarity ran through all the diagrams. It was found on investigation that the track at 9000 (which was in the hollow of a grade) had been reballasted after the profile levels were taken and raised by some unknown amount (probably something over a foot), accounting for the error. All the irregularities of the table are due to two defects of observation : (1) Lack of absolute precision in the track elevations, and (2) lack of exact correctness in the speeds read off from the dynamometer record, which was on a scale of $\frac{1}{16}$ in. per mile per hour, or 2 ft. of paper per mile run. To attempt to compute the resistance separately for each successive 1000 ft. is a very crucial test of the accuracy of the method, and a quite unnecessary one from a practical point of view. The computations over 5000 ft. stretches are very regular, illustrating that no other method can approach this in precision and certainty.

The weights of the trains tested were as follows, in tons of 2000 lbs.:

	Westinghouse.	Eames.	American.
25 box-cars, empty weight...........	301.07	261.41	344.79
12 loads, at 20 tons each	240.	240.	240.
Equalizing load, when used.	0.25	39.83	......
Dynamometer car, with 15 persons...	16.50	16.50	16.50
Way car, with 10 persons............	13.55	13.55	13.55
Total train.....................	571.37	571.29	614.84
Engine on drivers..................	26.54	26.40	25.02
" on truck....................	14.07	14.52	14.25
Tender empty......................	12.35	12.35	12.35
" "	15.15	15.15	15.15
Total engine and train..........	639.48	639.71	681.61
Of which there was braked..........	339.96	300.16	382.16
Per cent braked.....................	53.16	46.90	56.04

Every box-car truck but one, as well as the tender and engine drivers, had brakes on—a very unusual proportion.

All the trains had Master Car-Builders' standard axles (3¾ × 7 in.), except the Widdifield & Button, which had 3¼ × 7.

A full report of these tests, as prepared and computed by the writer, will be found in the *Railroad Gazette*, June to August, 1886. THE RESULTS OF A LATER SERIES OF TESTS IN 1887 (see *Engineering News*, May, June, 1887) were as follows:

		Average Speed. Miles.	Resistance. Lbs. per Ton.	
Tangent........................	1886........	16½	6.62	
	1887........	13¾	7.90	7.26
3° Curve........................	1886........	22½	8.46	
	1887........	16½	9.60	9.03
Lowest observed on Tangent....	1886........	20½	4.32	
	1887........	15	5.87	
Highest observed..............	1886........	11½	8.50	
	1887........	14½	7.51	

TABLE 160.

TRAIN RESISTANCE OF ENTIRE FREIGHT TRAINS, INCLUDING ENGINE.

[Giving the mean resistances in pounds per ton (of 2000 lbs.) computed as shown in Table 159, with the corresponding velocities in miles per hour.]

(Each of the resistances on tangent is the average on a run of 5000 ft. Each of the resistances on curves the average on a run of 2500 ft.)

	Resistances on Tangent.		Resistances on Curves.			Tangent Resist.*
	Vel.	Resist.	Vel.	Resist.	Curve.	
Westinghouse (C., B. & Q. cars).........	16.93	3.80	18.86	4.56	1.08°	4.02
	16.06	4.36	33.90	7.56	2.60°	6.26
	21.58	4.56	34.90	6.41	1.47°	5.68
	24.78	4.24	....	....	....	....
	21.55	4.44	....	....	....	....
Mean	20.51	4.32	26.33	6.07	1.75°	5.30
Eames (I., D. & S. cars) and Widdifield & Button (L.V.cars)	8.42	6.50	14.03	9.68	1.08°	9.14
	18.28	6.76	24.55	9.20	2.60°	7.90
	19.70	7.04	30.10	9.36	1.47°	8.63
Mean.............	16.82	6.84	21.70	9.42	1.75°	8.55
American (St. L. & S. F. cars)..........	9.62	9.30	13.03	8.08	1.08°	7.54
	13.72	7.88	24.45	10.40	2.60°	9.10
	....	....	30.75	7.84	1.47°	7.21
Mean	11.66	8.50	21.19	8.94	1.75°	8.07

* Tangent resistance determined by subtracting ½ lb. per degree of curve from the total resistance. Average degree of curve determined by determining degrees of central angle passed over by head and rear of train on given distance, averaging the two, and dividing by number of stations.

Velocities are in miles per hour; resistances in pounds per ton.

practicable freight speeds. The track was in fair but not remarkably good condition.

618. The conditions of the trains tested (which will be seen to have shown quite different results) were as follows:

1. *Westinghouse*† *train.*—Made up of old cars in excellent running order, with well-worn journals and wheel-treads. The performance of this train should fairly represent the ordinary conditions of practice.

2. *American train.*—Made up of entirely new and very heavy cars, which had only run some 300 to 500 miles since leaving the shop, and

† The trains are designated, for convenience, by the names of the brakes with which they were fitted, although these brakes had nothing to do with the tests.

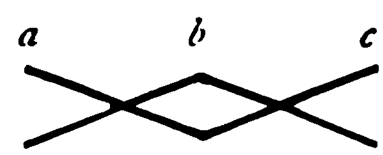
consequently had bearings and wheel-treads still comparatively rough, and *not* fairly representing the average conditions of practice.

3. *Eames train.*—Made up of fairly old but poorly built cars, and generally in rather inferior condition.

619. The effect of these differences in the trains is clearly visible in Fig. 154, where the Westinghouse train shows rather less than half the rolling resistance of the other two, or about 4 lbs. per ton for all speeds up to 25 miles per hour. The general fact that speed causes very little increase in train resistance up to speeds of 30 miles per hour is clearly indicated; and this many other indications tend to confirm, as notably various dynamometer tests made by the Pennsylvania, New York, Lake Erie & Western, Chicago, Burlington & Quincy, and other roads, where very low car resistances, running down to from $2\frac{1}{2}$ to 4 lbs. per ton, have been indicated, with little variation as an effect of speed.

These latter tests alone would leave the question open to much doubt, since they do not include any of the head or engine resistances, which at high speeds become more important than any other, but the tests given in Fig. 154 include ALL resistances and lead to the same conclusion so clearly as to be unmistakable.

620. The peculiar manner in which the Eames and American resistance lines on curves cross each other, as shown by the following sketch, may appear to indicate that there is something wrong in the computed results. This is by no means so. The anomaly may be thus explained:



(*a*) Each train was made up of 25 cars from the same road and built nearly at the same time.

(*b*) All freight cars are roughly built. The axles are not likely to be *precisely* parallel, except by accident. To have the axles enough out of parallel to precisely fit a 1° curve requires that the wheel-base shall be only $\frac{1}{1146}$ part longer on one side than the other, or $\frac{1}{20}$ in. A lot of cars built at one time are very likely to have the error all on one side.

(*c*) Resistances *a* and *c* (see sketch above) were on curves turning to the *right;* resistance *b* was on a curve turning to the *left.*

If, therefore, the American train curved most easily to the right, resistances *a* and *c* would be abnormally low, or very near the tangent rate, and resistance *b* abnormally high; while, if the contrary was the case, with the Eames train resistance *a* and *c* would be abnormally high, and resistance *b* abnormally low, or well down toward the tangent rate.

Whether this or other cause led to the variation, it is certain that it was an actual one, and the fairer plan, therefore, seems to be to take the average of both trains. The throttle of each engine was absolutely tight.

621. The experiments by the writer recorded in Appendix A were made by the same general method as those just described, and were the first in which the very low train resistances for trains in motion which are now generally admitted were observed. They indicated that the normal magnitude of the rolling-friction at speeds of 10 to 30 miles per hour was:

For passenger and loaded freight cars, ...	4 lbs. per ton
For empty freight cars and other light loads, ...	6 " "
For street cars and other still lighter loads, ...	10 " "
For freight trucks without load, ...	14 " "

The starting-friction is very much higher, rising to over 20 lbs. per ton in some cases. (See Appendix B.)

622. Some experiments on train resistance, both on curves and tangents, made in 1885 on the Breslau-Schmoltz line in Germany, apparently in an accurate and careful manner, but covering only the resistance of cars behind the tender and dynamometer car, gave still lower results than these, as shown in Table 161. The tests covered also the question of remedies for oscillation and the advantages of a device for radiating axles on curves, as to which nothing important was developed. The resistances are noticeable as being among the lowest ever reported for similar speeds. Similar tests on the Freiburg-Sulzbrunn line, with the same apparatus and by the same individuals, gave somewhat higher average.

Modern evidence to the same general purport as that which precedes might be multiplied almost indefinitely, but it appears needless to do so.

623. WE MAY CONCLUDE, THEREFORE, AS TO FREIGHT-TRAIN RESISTANCE—

1. The particular velocity adopted is wholly unimportant, both because it makes absolutely but little difference in the resistance, and because, if the resistances are mounting too high for the power of the engine, the speed can always be cut down at critical points. The total work in foot-pounds done to move

TABLE 161.

RESISTANCE OF EUROPEAN CARS (16 to 23 ft. rigid wheel-base).

[Reported in full in the *Railway Engineer*, Dec. 1884 *et seq*. Resistance in Pounds Per Ton.

SPEED. Miles Per Hour.	RADIATING AXLES.		FIXED AXLES.	
	Limits.	Average.	Limits.	Average.
12.4	2.0 to 3.75	2.65	2.42 to 3.75	3.09
21.8	3.97 to 4.19	4.08	3.97 to 4.85	4.19
28	5.07	5.07	6.17	6.17

the train is not affected enough to have any measurable effect on the cost of power (see par. 664).

2. The normal tangent freight-train resistance in summer, ENGINE AND ALL INCLUDED, is often, and perhaps usually, as low as 4 lbs. per ton, up to speeds as high as 25 miles per hour, running down in cases to 3 lbs. and even less; and, on the other hand, rising in cases as high as 6 or 8 lbs. per ton when the cars are in bad order, or against a head or side wind, or (as we are about to see) at winter temperatures; these latter figures being a fair working maximum for freight service.

Four pounds per ton will make a difference of some 2400 lbs. in tractive resistance with an average train of 25 cars, which will use up the adhesion of 4.8 tons of weight on drivers, or 12 to 20 per cent of the total load.

624. It is entirely uncertain how much of the so-called rolling-friction is journal-friction, and how much rolling-friction proper. The present probabilities are that most of it is journal-friction. Experimental determination of the rolling-friction proper, apart from all journal-friction, is a matter of the greatest difficulty, and has never been attempted. Journal-friction has been far more thoroughly investigated within the last few years, but until then the laws of it also had been but little investigated, and what investigation had been made was largely erroneous.

625. By some singular chance,—probably the beautiful simplicity of the laws developed, which only lacked correctness to make the laws of friction very easily understood,—some experiments made by M. Morin,* a French officer of artillery, in 1831, obtained almost universal acceptation as a final determination of the laws of friction. There is even at the present day (1885) hardly a single text-book of engineering, at least in English, in which these laws are not laid down as facts, yet they are now generally admitted to be entirely incorrect. They were in substance that the coefficient of friction was independent both of the pressure and of the velocity, so that, once determined, it was universally applicable. The range of the experiments was very limited, and Morin himself disclaimed any extension of them beyond the range of his experiments; but it is clearly proven that there are no limits nor conditions under which his laws are approximately true, since the coefficient varies materially both with pressure and velocity, with both lubricated and unlubricated surfaces, and with temperature and other conditions as well; as notably with the character of the surface, which makes any general coefficient of "iron on iron," or "iron on brass," for example, rather worse than useless.

* "Nouvelles Expériences sur le Frottement. Faites à Metz en 1831." Par Arthur Morin, Capitaine d'Artillerie. 128 pp., 4°, plates. Seconde Mémoire 1832, 103 pp., 4°, plates. Troisième Mémoire, 1833, 142 pp., 4°, plates.

626. Prof. R. H. Thurston was among the first, if not the first, to discover and announce the true laws of friction, in 1876–78, having made a large number of experiments on an ingenious machine of his invention. The writer, in the summer of 1878 made a series of tests of rolling-stock resistances, summarized in Appendix A, by dropping cars down grades and registering velocities electrically, in which he believes he was the first to discover and announce the variation in coefficient for loaded and empty cars and the aggregates of 4, 6, and 10 lbs., above mentioned, which at the time appeared quite without precedent, as Prof Thurston's results were not at that time generally known, and were not at all known to the writer. A large number of dynamometer tests on various roads were made shortly after, and in fact were then in progress,

Lbs per Ton Train Resistance.

(The velocity given for the rubbing-surfaces of 300 ft. per minute is equivalent to a train speed of some 34 miles per hour.)

FIG. 155.

showing the same low rate of 4 lbs. per ton or even less for loaded-car resistances, although empty-car resistances were less carefully determined. Shortly thereafter Mr C J H. Woodbury began tests of great interest for mill-work, which give strong confirmatory evidence of the above results as respects the general laws of friction, although not directly applicable to railroad practice. Finally, in 1883–4 Mr Beauchamp Tower made a series of elaborate and remarkable tests under the auspices of the Institution of Mechanical Engineers, which appear to have been the first made in England of a character to reveal the

errors of Morin's results. The Germans and French do not appear to have shown their usual scientific activity in this matter.

627. All these modern results agree in essentials with each other, although some have covered results not touched by the others. Their general results and indications are summarized in Appendix B. Mr. Woodbury's results* begin with the lowest pressures, and are shown in Table 162, and graphically in Fig. 155. For the very reason that this diagram is for pressures lower than ever occur in normal railroad practice, it is particularly interesting, since it furnishes a check on the conclusions which have been reached by other experimenters operating within the limits of railroad practice only, by beginning as it were at the foundation, and showing the law of change in journal-friction from 1 lb. per square inch of journal-pressure upwards. There has been added below the diagram a line showing the equivalent in pounds per ton of train resistance to the abstract "coefficients of friction" given, as being a unit better suited for our immediate purpose.

TABLE 162.

COEFFICIENTS OF FRICTION WITH VERY LOW PRESSURES, AND EFFECT THEREON OF TEMPERATURE.

[Abstracted from records of tests of C. J. H. Woodbury.]

Pressure Per Sq. In.	Coefficient of Friction.		Total Friction at Temperature of—		Per Cent of 100° to 40°.
	40°.	100°.	40°.	100°.	
			lbs.	lbs.	
1	.538	.138	.538	.138	25.6
2	.299	.080	.598	.160	26.8
3	.211	.060	.633	.180	28.5
4	.167	.050	.668	.200	30.0
5	.140	.044	.700	.220	31.3
6	.122	.039	.732	.234	32.0
7	.109	.036	.763	.252	33.0
8	.098	.034	.784	.272	34.7
9	.090	.032	.810	.288	35.7
10	.084	.030	.840	.300	35.8
15	.063	.025	.945	.375	39.7
20	.053	.023	1.060	.460	43.3
25	.046	.021	1.150	.525	45.7
30	.041	.020	1.230	.600	48.8
35	.038	.019	1.330	.665	51.1
40	.035	.018	1.400	.720	51.5

* For complete paper, which is full of interesting information on friction, see "Measurements of the Friction of Lubricating Oils," by C. J. H. Woodbury, Trans. Am. Soc. M. E., 1884–85.

628. The diagram is especially useful to afford some indication as to the comparative train resistance in winter and summer, as to which there are no experimental records. Since the diagram fixes, as it were, a superior limit for the friction of railroad journals, we might, on studying it, fairly draw three conclusions :

1. Since friction can in no case be less than zero, lines representing all possible loads on railroad journals must lie in the narrow space at the left of the diagram between the zero line and that for 40 lbs. per square inch pressure, which is the last given. This means that all railway-journal friction ought to lie between these narrow limits :

Temperature of journal.	Coefficient of friction.	Pounds per ton train resistance.
40° Fahrenheit...........	0 to .035	0 to 7.0 lbs.
100° Fahrenheit...........	0 to .018	0 to 3.6 lbs.

This closely corresponds with the result of all the latest tests, which show from 3½ to 6 lbs. per ton resistance.

629. 2. Within the temperature limits of 40° and 100°, the effect of the higher temperature is to decrease materially, and of the lower temperature to increase materially, the amount of loss by friction. At 40 lbs. per square inch the friction is nearly twice as much at the lower temperature, while at still lower pressures of 1 to 10 lbs. per square inch it is from three to four times as much. Extending the indications of these tests to the higher pressures of railway practice, we might expect that the effect of a fall of temperature in the journals from 100°, which we may call an average summer temperature, to 40°, which we may call an average winter temperature, would be to make journal friction in summer and winter railway service compare somewhat as follows :

	Loaded.	Empty.
Summer, as shown by various tests, say..........	4 lbs.	6 lbs.
Winter (not directly shown by any tests), say......	5½ to 6 lbs.	8 to 9 lbs.

630. Whether this conclusion be true or not cannot be proven by direct evidence, for lack of recorded train-resistance tests which have been made in cold weather, but the circumstantial evidence that some change of this kind takes place is very strong. Among such evidence is one small fraction of the series of tests by Mr. Beauchamp Tower, above alluded to, for determining the effect of temperature on journal-friction. The loads and journal-speeds in this case closely paralleled railway practice, but the lubrication was vastly more efficient, being by a *bath* of lard-oil. Lard-oil is affected by temperature much as are ordinary railroad lubricants, but the superior method of lubrication, in addition to giving rates of friction which are far below the possibilities of railway practice, would be likely to have the effect of exaggerating the beneficial effect of high temperature, since the more perfect the supply of oil, the greater might be expected to be the advantages of great fluidity.

Nevertheless, with these allowances remembered, some of Mr. Tower's results, as summarized in Table 163, are very instructive. Translating coefficients of friction into pounds per ton of train resistance, as in Fig. 155, by multiplying them by 200, and translating the journal-speeds into train-speeds by multiplying by 10 (these methods being approximate only, but sufficiently exact), we have in Table 163 some very definite indications of the effect of temperature on axle-friction.

631. To draw any positive conclusions from this table we must make a certain "scientific use of the imagination," by making allowances both in the temperatures and in the observed friction for the difference in manner of lubrication. As these allowances might or might not be correct, we will not attempt them; but it is clear that, be the allowances thus made what they may, these results support the general conclusion strongly, that the external temperature of the air may have a most important influence on the normal rolling-friction, as do experiments by Professor Thurston and others. On the other hand, there are many experiments which, at least in appearance, would tend to controvert these conclusions, for one has only to look long enough to find experimental records to support or controvert almost anything. But such controverting evidence is in this case not abundant, nor of the highest class, and as a general rule the apparent discrepancies all result from two apparent anomalies which are in no respect inconsistent with what has preceded:

1. At a certain temperature not far above 100° Fahr., and with some fluid oils below it, the law changes, and increase of temperature causes a rapid increase of resistance.

2. At very slow speeds, especially when combined with very high pressures, the law often changes, and a higher temperature has an injurious effect, apparently because a certain viscosity is necessary for efficient lubrication under such circumstances.

TABLE 163.

EFFECT OF TEMPERATURE ON JOURNAL FRICTION.

[Deduced from tests of Beauchamp Tower; bath of lard oil; load, 100 lbs. per sq. in. (about that of an ordinary empty freight-car journal.)]

	POUNDS PER TON OF TRAIN RESISTANCE AT SPEEDS IN MILES PER HOUR OF—						
Train speed..	8.8	13.2	17.6	21.9	26.3	35.1	39.5
At 120° Fahr.	0.48	0.58	0.70	0.80	0.88	1.02	1.08
At 60° Fahr..	1.18	1.68	2.06	2.38	2.60	2.96	3.12
Difference..	0.70	1.10..	1.36	1.58	1.72	1.96	2.04

632. Zero temperatures are not favorite ones for dynamometer experiments, but experience in the running of trains in winter and summer indicates in the most positive manner that summer trains must be cut down by two to four cars in winter, or say 10 to 15 per cent, in order to run them at all. This practice has not become universal without some real necessity; but it is more difficult to account for the necessity than is generally realized, for some of the explanations which are given will certainly not hold water, as pointed out in par. 345. It need only be added, that the loss by radiation from the locomotive will hardly explain any part of this need for cutting down trains, since the difference between winter and summer temperatures is a small and unimportant one to the locomotive, though a very important one to the human body.

633. Let us see how radical is the difference in its effect on them. The human body can manage to sustain for a short time a temperature of say 40° below zero, or 138° below its natural temperature, and it can do this only when "lagged" with skins and such like, to the last degree of perfection, at every exposed point. The boiler is subjected to an equally unpleasant extreme of temperature when the external temperature is $350 - 138 = 212°$ Fahrenheit, or just hot enough to cause water to boil in the open air. To get a fair parallel, we must consider how much warmer the average man would think it with the temperature 140° below zero than when it was down to 200° below zero. It is not probable that he would find that the difference was of great consequence.

To be sure, the fire inside the boiler is more efficient than the fire inside the human body, but the demands on it are greater and the difference of winter and summer less. The average winter temperature of Pittsburgh, for example, is about 38° and the average summer temperature 72 degrees, so that we have as the difference between the inside and outside temperature of the boiler—

In winter....	350°	−	38°	=	312°
In summer....	350°	−	72°	=	278°
Difference....			34°		34°

or about 11 per cent.

This difference is far too small to explain the necessity for any material difference in winter and summer loads. Assuming that as much as 20 per cent of the heat generated is lost by external radiation, which is a large estimate, not more than 2 per cent difference of load could be accounted for in this way.

634. We seem driven, therefore, as a net result of all the preceding, to this interesting and important conclusion, to directly support which there is, as already stated, little or no experimental evidence, although the circumstantial evidence in favor of it is very strong: that a difference in the rolling-friction of cars is the chief reason why trains must be cut down in winter. As this

probably results from difference of temperature of the journals, and this again from radiation from the boxes of the heat which the journals are constantly generating, and as radiation can be checked by a very slight covering which will hold a little dead air around a hot metallic surface, we have in these facts indications which might lead to the important practical conclusion that some very slight covering, which would merely check radiation from the journal-boxes somewhat, might have an appreciable effect on the loads which can be hauled in severe cold weather.

635. In Appendices A and B will be found further and more detailed information as to the laws of journal-friction, and especially as to the important question of starting trains. The normal journal-friction, under favorable conditions, as determined in various series of tests, is summarized in Appendix B as follows, for velocities greater than 10 miles per hour, or 90 ft. per minute, journal-speed:

	Lbs. per ton.
Beauchamp Tower, bath of oil	0.278
" " pad or siphon	1.9
Thurston, light loads	2.75
" heavy loads	1.75
Wellington (gravity tests of cars in service), light loads	6.0
" " " " " heavy loads	3.9
" direct tests (as shown in Appendix B)	{ 5.1 3.7
Thurston, inferior oils ("Friction and Lubrication," p. 173)	{ 4.8 3.0
Morin, continuous lubrication	6.0 to 10.8

636. The great discrepancies in these results will be seen to point directly to one conclusion—that the character and completeness of lubrication seems to be immensely more important than the kind of the oil, or even pressure and temperature, in affecting the coefficient of friction. Mr. Tower found that lubrication by a bath (whether barely touching the axle or almost surrounding it) was from *six to ten times* more effective in reducing friction than lubrication by a pad. By immersing the journal in a bath of oil Mr. Tower succeeded in reducing the coefficient in a large number of tests to as low a point as 0.001—equivalent to only 0.2 lb. per ton of tractive resistance; and the general average in the bath tests, under all varieties of load and speed, is given as only 0.00139, or 0.278 lb. per ton, against 1.96 to 1.95 lbs. per ton with siphon lubricator, or pad under journal. These results are very far below any heretofore reported.

637. The overmastering effect of minute differences in the condition of the lubrication was curiously shown in two ways in Tower's experiments:

1. It was accidentally discovered that with bath lubrication the bearing is actually floated on a film of oil between the lubricated surfaces, which is so truly a fluid that it will rise through a hole in the top of the bearing in a continuous

stream and exert a pressure against a gauge equal to more than twice the average pressure per square inch on the bearing. This is precisely what theory would require if the lubricant were a perfect fluid.

2. Tower's apparatus required that the journal should be revolved first one way and then the other. It was found that the friction was always greater when the direction of motion was first reversed. The increase varied considerably with the newness of the journal. "Its greatest observed amount was at starting, and was almost twice the nominal friction, and it gradually diminished until the normal friction was reached, after about ten minutes' continuous running. This increase of friction was accompanied by a strong tendency to heat, even under a moderate load. In the case of one brass which had worked for a considerable time it almost entirely disappeared." It is with apparent justice concluded that the phenomenon must be due to the interlocking, point to point, of the surface fibres after having been for some time stroked in one direction.

638. It appears not impossible, therefore, that a great further reduction in the axle-friction of trains, as well as a great saving of oil, may result, within a few years, from the adoption of something better than the crude and wasteful axle box which is now common. The objections to it are:

1. It leaks badly at the back, around the axle, letting oil out and grit in. Therefore—

2. The oil has to be frequently renewed, requiring a loose lid in front, from which more oil escapes and more grit gets in.

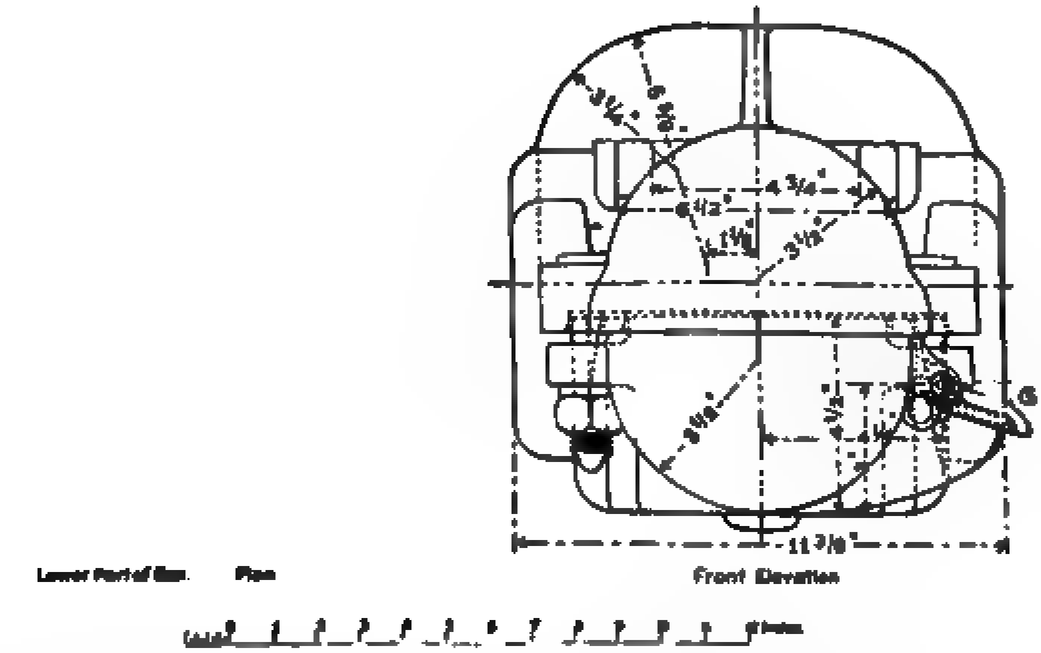
From this it very naturally results that in spite of the large expense of about a cent per train-mile (Table 78) for oil there is often very little of it where it is wanted, and that dirty and gritty; while, on the other hand, the ties and road-bed are saturated with it from one end of the United States to the other.

639. In Figs. 156–159 is shown a French oil-box which obviates many of these objections and has made the very remarkable record given below. The Germans have similar oil-boxes in extensive use. The oil reservoir is entirely below the axle, so that oil cannot escape, and it is supplied to the bearing by a pad fed by wicks. Could an oil-tight stuffing-box be used at the back of the box, and the box be kept completely full of oil, it is more than probable that even greater reduction of axle-friction and waste of oil would follow.

The lower half of these boxes is furnished inside with a partially horizontal diaphragm in the portion toward the wheel, for the purpose of preventing the forcing out of the oil by violent side blows. They have proved so efficient that the consumption of oil has fallen from 2.3 ounces per 1000 miles to less than one fourth that amount (41.25 grammes per 1000 kilomètres to 9.93)—a most remarkable showing, and a marvellous contrast to the results obtained here. The dust guard is formed of five to six thicknesses of fluffy woollen cloth, held between two leather diaphragms by screws like those used for shoe soles. The diaphragms are in halves, and are pressed up against the

axle by steel springs behind them, and the leathers on opposite sides of each half diaphragm break joints with those on the other half.

The oiling cushion in this box has its oiling plush firmly tacked to a beech



FIGS. 156–159.—STANDARD JOURNAL-BOX OF THE EASTERN RAILWAY OF FRANCE.

block, and to this plush are fastened several little tufts projecting above its surface and keeping the plush from matting down by too hard pressure against the journal. The plush is of wool with a long silky warp.

640. The important question of the comparative resistances in starting trains is discussed so fully in Appendices A and B that it appears unnecessary to devote space to a repetition of the same matter here. From all the facts there given the following conclusions may, it is believed, be drawn:

1. The resistance at the beginning of motion in each journal is equal (as before stated) to about 20 lbs. per ton, or say 15 lbs. per ton over the average friction in motion. Except, therefore, for the elasticity of the springs or the equivalent effect of the "slack" which always exists in freight trains, enabling the cars to be set in motion one at a time, such trains as are usually hauled could not be started at all by the locomotive.

2. A velocity of 0.5 to 3 miles per hour, or, as an average, 2 miles per hour, must be attained before the journal-friction falls to 10 lbs. per ton, or 5 lbs. above the average motion.

The average during this period may be taken at 12 lbs. per ton.

3. At 6 miles per hour the journal-friction is at least 1 lb. per ton higher than at usual working speeds. The average journal-friction between 2 and 6 miles per hour may be taken as at least $2\frac{1}{2}$ if not 3 lbs. per ton higher than the normal.

4. During the period of getting up speed, the normal law of acceleration of velocity is so interfered with by the varying coefficient of friction that the velocity attained at any given point may be rudely taken as directly proportional to the distance run, so that the increase of velocity would be more correctly represented graphically by a right line than by the parabola tangent to the horizontal line of normal velocity in motion which theory requires.

641. Assuming these facts, we having the following conditions in a freight train which is so heavily loaded that it may be assumed to have to run 3340 ft., or $\frac{5}{8}$ of a mile, to acquire a velocity of 10 miles per hour.

1. The average velocity will be under 5 miles per hour and the time occupied over 7.6 minutes.

2. The increased tractive force needed merely to accelerate the speed will be 2 lbs. per ton; since communicating that velocity is equivalent (Table 118) to lifting the train through 3.34 ft. vertically, and $\frac{3.34}{3340} = 0.10$ per cent grade = a resistance of 2 lbs. per ton.

3. For the first one-fifth of this distance, or 668 ft., the total demand upon the tractive power is—

2 lbs. per ton for acceleration.
12 lbs. per ton for extra rolling-friction.
—
14 lbs. total *additional* tractive resistance, equal to a grade of 0.70, or 37 ft. per mile.

4. For the next 1336 ft. the total demand upon the tractive power is similarly found to be 4.5 to 5 lbs. per ton over the normal, equivalent to the effect of a 0.225 to 0.25 per cent grade, or 12 to 13 ft. per mile.

642. These grades, therefore, represent the reduction at stations or stopping-places which it is essential to make to fully and certainly equalize the demands upon the tractive power of locomotives while in motion and when getting under way. The fact that such heavy reduction of grade at stations may be said never to exist, while yet such heavy trains are hauled, is due in part to the use of sand in starting, in part to the greater *starting* traction which is realized in practice from the same average cylinder pressure (see end of Appendix B), and in part to the fact that the full adhesion of the locomotive is not used up on the open road (par. 557). To utilize to the utmost the power of locomotives, and to make the hauling of heavy trains easy, such reductions are the first thing which should be attended to in laying out a new road or in improving an old one.

Wherever possible the reduction of grade at stations should be liberal, since there is in no case danger of having it too great for convenience. On the other hand, when the lower grades at stations are only obtainable at the certain cost of higher grades between stations, then it becomes necessary to be more cautious, although the tendency will always be to have the starting resistances the true limiting cause.

643. *Effect of Size of Wheel and Journal.*—Theoretically, the less the diameter of the journal and the larger the diameter of the wheel the less the axle-friction. The standard diameter of car-wheels in America is 33 inches, with a very few only (chiefly on the Baltimore & Ohio lines) of 30 inches, and with a still smaller but increasing number of 42-inch wheels in passenger-car service. The weight of the latter is more than double that of 33-inch wheels (say 1200 lbs. against 550, as an average) and their primary purpose is to promote easy riding of cars.

The Master Car-Builders' Association standard journal is $3\frac{3}{4} \times 7$ inches, giving a nominal bearing-surface (the horizontal mid-section) of $26\frac{1}{4}$ sq. in. A very few 4×8-inch journals, giving 32 sq. in. bearing, are in use for cars carrying very heavy loads, and a very large but decreasing number smaller. down to as small as $3\frac{1}{4} \times 6$, giving 19.5 sq. in. of bearing.

The maximum loads which are carried in practice on these journals, allowing eight per car, may be estimated as follows:

Journal.	Square Inches Area.	Maximum Load.	Load Per Square Inch.
Maximum, 4×8........	$32 \times 8 = 256$	64,000	250 lbs.
Standard, $3\frac{3}{4} \times 7$........	$26\frac{1}{4} \times 8 = 210$	52,500	250 "
Minimum. $3\frac{1}{4} \times 6$........	$19.5 \times 8 = 154$	38,500	250 "

33

As an average of the entire service of the car these loads will hardly in any case exceed 200 lbs. per sq. in., but they will often run up to 300 lbs. This pressure, however, is very unequally distributed, being greatest (about twice the average) at the top of the journal and running down to nothing at the sides. The bearing, in fact, for this and other good reasons, is never made to cover the whole semicircular top of the journal. For example there are only 24.94 sq. in. of bearing-surface in the American standard journal-bearing against 26¼ sq. in. in the section of the journal itself.

644. The only purpose in increasing the size of the journal is to di-

FIG. 160.—USUAL FORM OF AMERICAN CAR-WHEEL, JOURNAL, AND JOURNAL-BOX.

[53 is the so called *dust-guard bearing* of the axle, surrounded by a flat, square *dust-guard* of wood, leather, or vulcanized fibre, which is slipped in from above through a slot in the casting not shown in the cut (in which respect it is incorrect), and constitutes the only protection against the escape of oil at the back. The oil freely escapes through this dust guard until it has drained out so far below the level of the under side of the axle that there is no more to escape.]

minish the pressure per sq. in. so as to prevent heating. Experience has amply shown this to be necessary, with such lubrication as is attained in

America, because, although 99 per cent of the car mileage may be said to be made with journals in good order, and in fact with surfaces in a high state of perfection, yet the inconvenience and danger resulting from possible heating of the remaining one per cent is the important thing to obviate. In France and Germany, where much more carefully constructed axle-boxes, insuring far more reliable lubrication, are in use than here, as shown in Figs. 156 to 159, far higher pressures are likewise in use, without evil results, up to fully double American practice, and with great economy of lubricants; but the crude form of axle-box usual in this country, shown in Fig. 160, permits fully nine tenths of the oil supplied to the journal to drip out upon the track before it has done much service.

645. The coefficient of train resistance due to axle-friction

$$= \frac{\text{coeff. of fric.} \times \text{diam. of axle}}{\text{diam. of wheel}} \text{ (see Fig. 161), and this} \times 2000 \text{ or } 2240$$

= journal train resistance in lbs. per ton. With the same axle, therefore, by increasing the diameter of the wheel from 33 to 42 in. we should decrease axle-friction to $\frac{33}{42}$ of its former amount, or about $\frac{4}{5}$. With the same wheel, the comparative axle-friction is directly as the diameter of the journal.

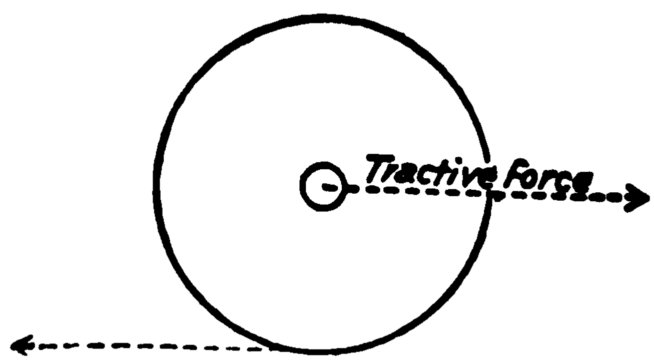


Fig. 161.

646. If the average journal-friction in motion be taken at 4 lbs. per ton, the larger wheels, therefore, will save about 0.8 lb. per ton of rolling-friction, but they will add possibly 10 per cent to the weight of the car, and therefore to grade resistance. Hence, wherever the grade resistance exceeds about 8 lbs. per ton (= that on a 0.4 per cent grade; 21 feet per mile), the use of 42-inch wheels is a losing operation, so far as mere train resistance in motion is concerned, but there still remains as a net gain the improvement in riding qualities of the cars and in ease of starting—both very important gains.

647. Many circumstances indicate that the rolling-friction proper, between the rail and wheel, is an element of considerable importance in the aggregate of the so-called "rolling friction." One is the known and great effect of the condition of the track on the resistance. It is probably largely due to this cause that modern determinations of rolling-friction, both in this country and abroad, are so much below what was formerly the assumed average. Another is the ordinarily very perfect condition of railway journals and the very low coefficients which have been obtained by Thurston, Tower, and others for journal-

friction proper, as above given. Another is the high tractive coefficients of wheeled vehicles with very small axles and very large wheels on the most perfect roads. On the other hand, the close correspondence of the laws of variation in rolling and journal friction, together with the laws of variation in journal-friction only, seem to indicate quite the contrary. Thus, in both cases, as the load or the velocity decreases the coefficient of resistance increases, and at about the same rates (see Appendix B).

648. A plausible argument may be made to show that no theoretical loss whatever exists from the compression of a perfectly elastic substance, such as a rail may be assumed to be, and to a great extent the permanent way as a whole, under a rolling load. In Fig. 162, the compression at any point of the surfaces in contact, wherever it may be, is proportional to ordinates from the line *CC* to the periphery of the wheel *P*. The elastic resistance is in proportion to these ordinates, and the semi-segments *FF'* represent in magnitude and position the total elastic forces operating to retard and to accelerate. The resultants *R* and *R'* of these parallel forces must pass through the centre of gravity of these semi-segments *F* and *F'*, and must each be equal to half the total load resting on the wheel. It appears to follow clearly from the figure that the moments of these accelerating and retarding forces are equal, so that they neutralize each other.

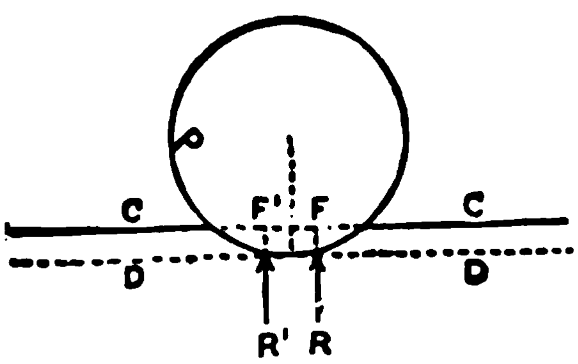


FIG. 162.

The error in this reasoning is in part that at high speeds the element of TIME comes in to modify the elastic resistances, increasing that in front of the wheel because it must be set in motion, and decreasing that behind the wheel because the elastic resistance requires time to act, and hence cannot follow up the wheel with its full force. In part the error is that any irregularity of surface causes an irregularity of motion which is known to very seriously affect both wear and tear and friction.

Any attempt to determine theoretically the amount as well as the nature of this loss would, of course, be impracticable.

649. The work of Josef Grossman, Engineer of the Austrian Northwestern Railroad, on "Lubricating Materials and Metals for Bearings" (Wiesbaden, 1885), treats its subject with a good deal of elaboration, historically and analytically, and among other matters discusses quite fully the question of train resistance, although not always with correctness and good judgment. His results indicate, however, that the axle-friction is at any rate a very small element. In this connection he cites a remarkable result of some Bavarian experiments, in which by greasing the rails on the curve of 100 metres (337 ft.) radius a reduction of the total curve resistances of 96 per cent was attained: 61 per cent of the total resistance due to the curve disappearing when the *inner*

edge of the head of the outer rail was greased, and 31 per cent more when the other rail was greased.

The striking correspondence of these experimental results with those deduced theoretically in pars. 301–320 *et seq.* is notable.

THE VELOCITY RESISTANCES.

650. The best evidence that we have warrants the all but universal assumption that train resistance varies as the square of the velocity, or that its equation is of the form

$$R = fv^2 + c.$$

This is still merely assumption, not only as respects train resistance as a whole, but as respects each separate constituent element. Air resistance, for example, is known by observations on projectiles to vary more nearly as the cube of the velocity, when the latter is very great; but at all ordinary velocities it appears to vary very nearly as the square, and as respects oscillatory resistance, we know absolutely that the amount of destructive work (or of any other kind of work) which a train is capable of doing, either by a dead or glancing blow, is directly as the square of the velocity. These two elements constituting together the ordinary "velocity resistance," it is but natural to conclude that the aggregate also varies as the square of the velocity, and all but certain that it does, although it may very easily be as $v^{1.9}$, or $v^{2.1}$, or even $v^{2.2}$, or may fluctuate between these powers at various speeds or according to circumstances. There have been various formulæ put forth, and some of them on very high authority, differing widely from this form, some of them giving the velocity resistance directly as v, and others (only one of which is known to the writer) as v^3, but both of these assumptions lead to absurd results when extended to very high speeds, and are unquestionably erroneous.

651. One instance of the former (as respects the train behind the engine) is given in par. 662. On the other hand, a formula deduced from Bavarian experiments in 1876, on a large and costly scale, reported by the late Baron von Weber in a somewhat informal paper,* led to the most absurd results, not necessary to detail here.

652. As a rule, no attempt is made in train-resistance formulæ to separate the aggregate velocity resistance into its constituent elements, although in some cases they are in such form as to assert or imply that the velocity resistance is either all oscillatory or all atmospheric. A formula devised by Mr. Wm. H. Searles, which has been adopted as the

* See *Railroad Gazette*, June 11, July 16, 1880.

basis for the computations of this volume as having a truly wonderful range of application to all speeds, conditions, and classes of trains, even if it is not precisely correct, is open to the sole serious objection (and that chiefly theoretical) that it in effect assumes all velocity resistance to be oscillatory, or uniform per ton, regardless of the form of the cars (see pars. 657–8); while, on the other hand, formulæ proposed by Mr. O. Chanute (in Haswell's "Pocket-Book") are distinctly based on the assumption that the velocity resistance is wholly atmospheric. Both of these assumptions are unquestionably erroneous, although which is most so must remain doubtful.

653. The writer has conducted the only tests as yet made, and known to him, which have been distinctly directed to the end of determining the amount of each element of train resistance separately, and owing to the delicacy of the apparatus by which they were made, and the extreme care used in computing them, he believes them (with perhaps a natural bias) to be still the most trustworthy indication in that respect. These experiments are given in full in Appendix A, and their general results are shown graphically in Fig. 163, their most striking feature being perhaps the positive evidence that atmospheric resistance is at least a less proportion of the velocity resistance than is commonly assumed, and that the resistance arising from oscillation and concussion, whatever its exact cause and nature, is a materially more important element.

654. Nevertheless, there is a fact tending to disprove these conclusions, viz., the enormously greater indicated power of locomotives at high speeds than that transmitted backward to the train as determined by a dynamometer. Table 164 gives one record illustrating this fact—a test trip of a fast express train on the New York Central & Hudson River Railroad, made by Mr. P. H. Dudley, in which it will be seen that only some 45 per cent of the indicated power passed back of the dynamometer-car to the train at 53 miles per hour. Figs. 164, 165, giving the results of some elaborate French tests, show a still higher proportion of engine-friction. Other tests of the kind show, according to the speed, from 40 to 75 per cent. The whole subject is still involved in much obscurity and doubt, but Figs. 164, 165 and Table 165 will illustrate how very important an element the head resistance is at high speeds.

655. According to the best evidences which the writer has been able to secure, the ordinary working MAXIMUM of train resistance, under SOMEWHAT ADVERSE conditions as respects wind and surfacing of track and rail, may be considered to be not un-

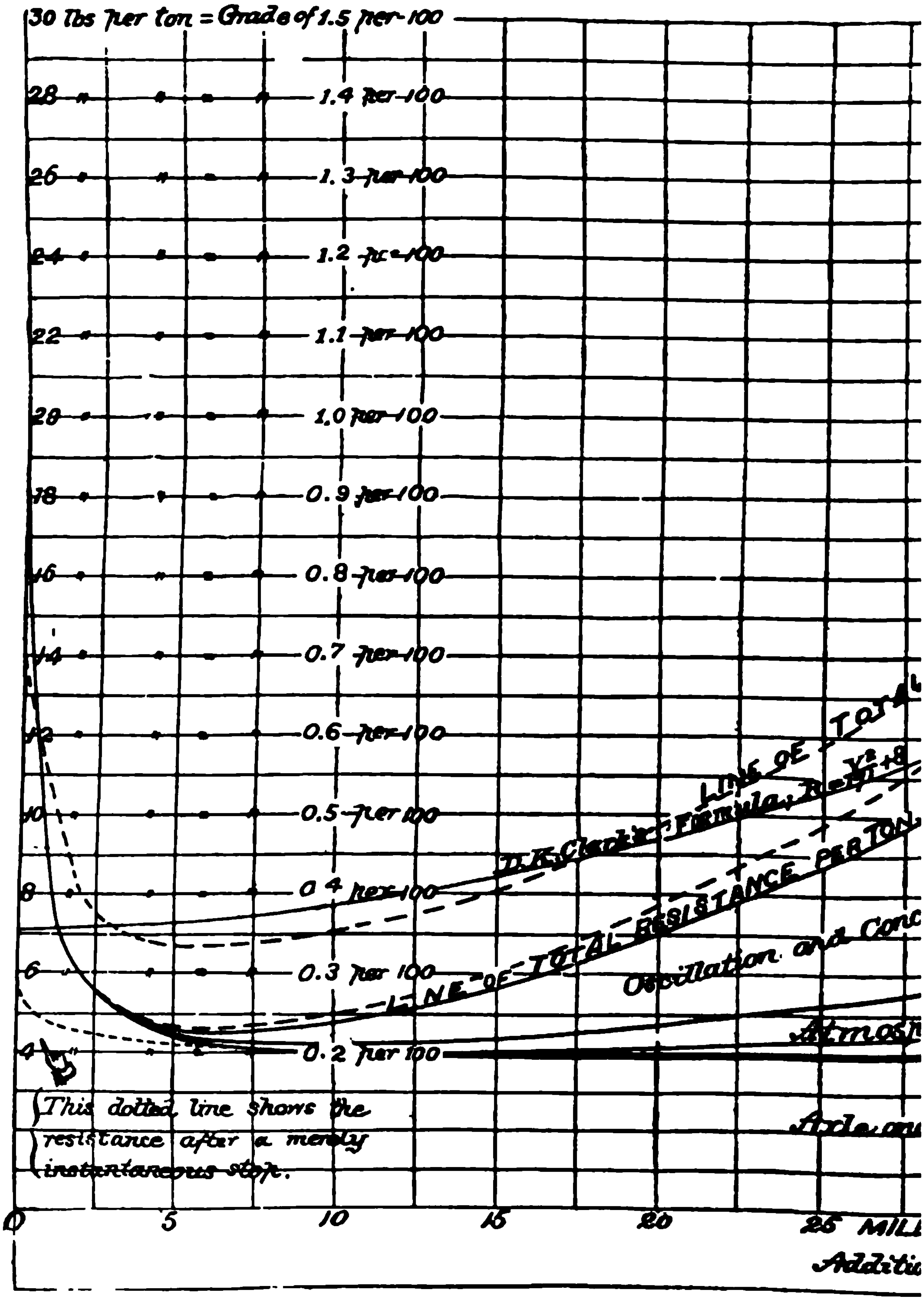
FIG. 163.

DIAGRAM SHOWING THE RESISTANCES PER TON C

AS DEDUCED FROM EXPERIMENTS ON THE LAKE SHORE & MICHI

Conducted by A. M. Wellin

[For original paper, see Trans. Am. Soc. C.E., Vol. VIII., No. CLXXVII.



D. K. Clark's formula, shown hereon, is one of the oldest and best know modern tests indicate that it is far too high at low speeds, and on the whol *et seq.*

esistance formulæ, and was for a long time regarded as standard. More
low at high speeds, although the latter is more doubtful See par. 655

developed of 750 to 800 H. P., and taking the average for the four miles 13–16, on which the grade was level and the speed uniform, we obtain:

Average speed, miles per hour, 51.43.	Average horse-power expended on— Train.	Engine.	Total.	P. c. eng.
	340	426	766	55.61
	lbs.	lbs.	lbs.	
Equivalent total traction resistance	2,479	3,106	5,585 (= ⅙ adhesion.)	
Ditto, in lbs. per ton	9.92	49.25	17.8	

This is considerably lower than Table 166 indicates, which is about 30 lbs. per ton; but one possible explanation of this discrepancy is that Mr. Dudley's table does not warrant his declaration that "at 50 miles per hour the traction was 2800 to 3000 lbs.," but indicates only 2500 lbs. This difference alone would add 1⅛ to 2 lbs. per ton to the resistance.

Mr. Dudley's engine and head resistance, as an average of all his record (not all given here), amounts *per engine* to $0.83V^2$ lb. The writer's tests (see Appendix A and Fig. 165) give a somewhat smaller result for the engine resistances, viz.:

	Lbs. per engine.
For head resistance........................	$0.28V^2$
For oscillation and concussion..............	$0.35V^2$
Total..................................	$0.63V^2$ + 4 to 8 lbs. per ton constant.

By comparison of a variety of evidences, however, the writer believes that $0.83V^2$ lb. comes very close to giving the actual total velocity-resistance of the engine at high speeds, and the rapid inroads which this rate makes on the power of the engine is shown in Table 165.

fairly expressed by the single formula of Mr. Wm. H. Searles just referred to and given below. For the more favorable conditions it gives unquestionably far too high resistance; as for example, for a train of 313 tons, as in Table 164, at 50 miles per hour, it gives a tractive resistance of 30 lbs. per ton for the entire train, or 9390 lbs. total tractive resistance, equivalent to 1280 horse-power, whereas the actual horse-power, as given beneath the table, was less than 800. Further evidences to the same effect are given in par. 659 *et seq.*, below; but the RATIOS of the resistances at various speeds are of more practical importance than their absolute amount, and these will not be affected importantly by any reduction in the latter. Moreover, nearly all our experimental evidence is based on observations taken under the most favorable conditions for low resistance, and in the case of European tests with trains of much smaller cross-section and with cars much nearer together. The bounding rectangles of the average American and European passenger cars (a fairer basis of

FIG. 164.—VARIATION IN RESISTANCE *Per Ton* FOR VARIOUS LOADS.

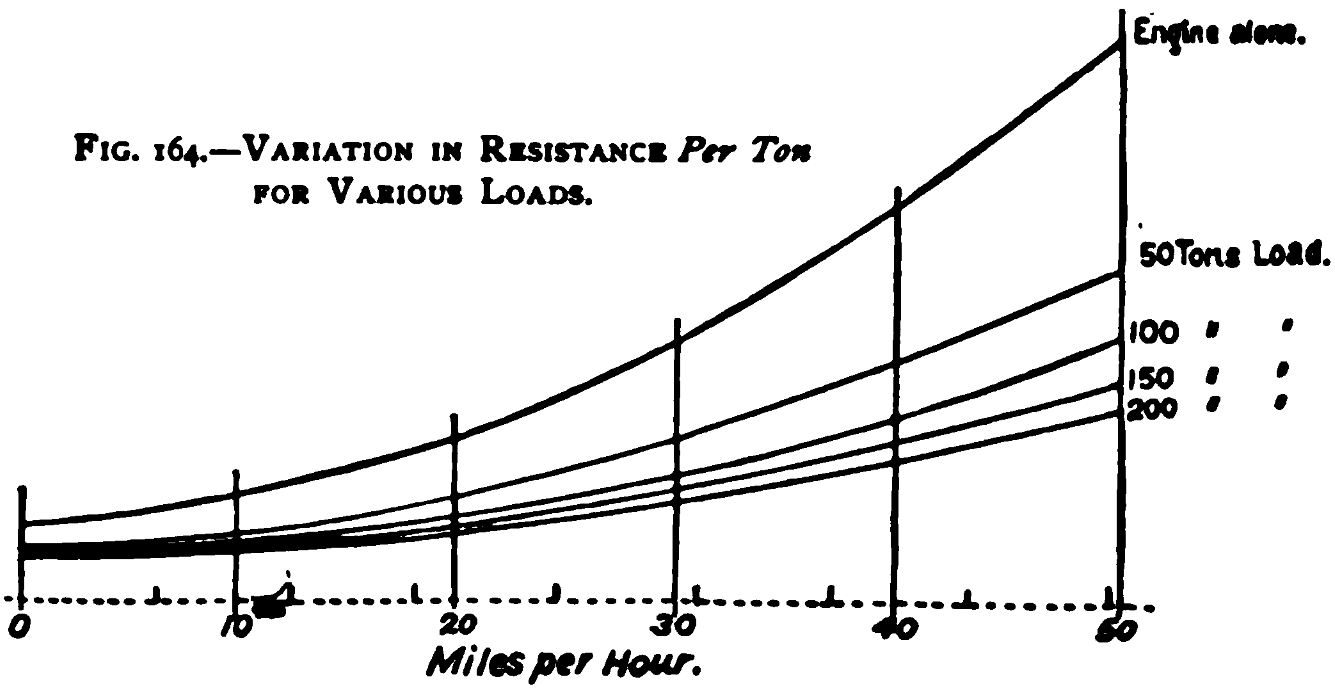
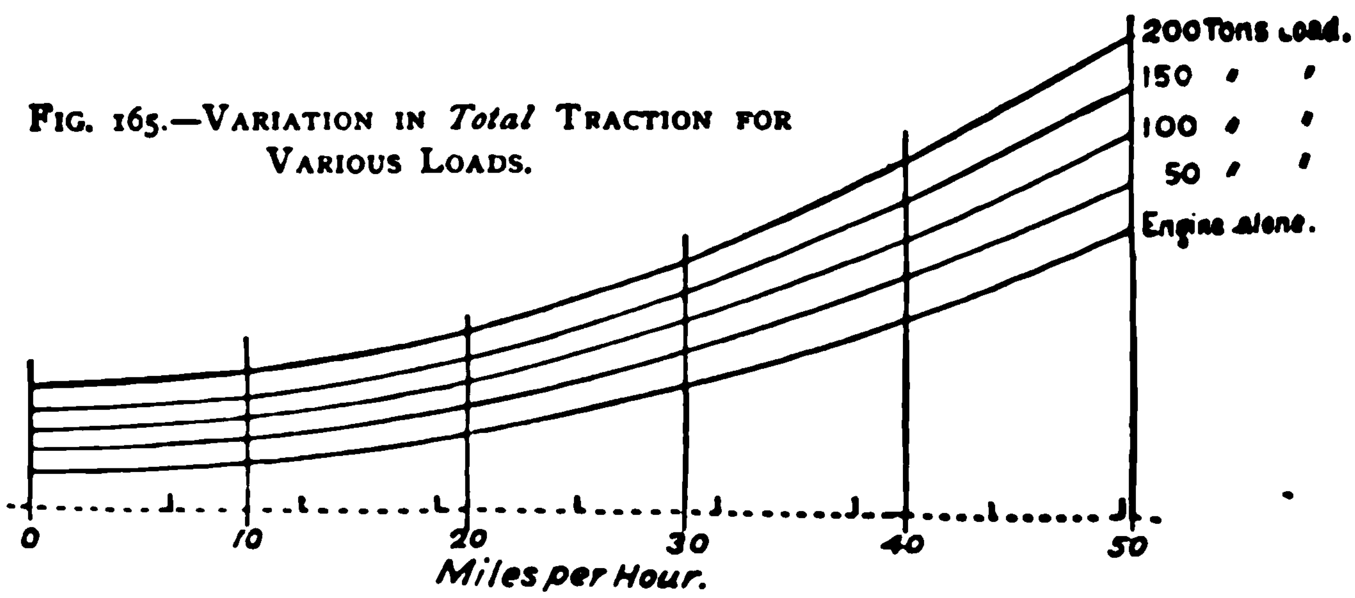


FIG. 165.—VARIATION IN *Total* TRACTION FOR VARIOUS LOADS.



FRENCH TESTS OF TRAIN RESISTANCE AT LOW VELOCITIES.

[From *Annales des Ponts et Chaussées*, May, 1886. "Études Dynamométrique," par M. Desdoint, Ing. de la Marine, adjoint a l'Ingénieur en Chef du Matériel et de la Traction des Chemins de Fer de l'État.]

The paper showed resistances at low ordinary speeds of—	Lbs. per ton.	
Passenger trains, 40½″ wheels, 3⅛ × 7″ axles, 4 tonnes per axle, ...	3.2 / 3.0	3.1
Freight " " " 5 " "	3.4 / 3.0	3.2

Temperature of axles 53.6° Fahr.

At still lower velocities of 5 ft. per second (3⅛ miles per hour) the resistance varied from 4.4 to 5.4 lbs. per ton, this being in fact due to the lower journal speed, as observed by the writer in his tests (par. 640 *et seq.* and App. A and B), and not at all to their being "valeurs toutes exagérées comme on va la voir," as suggested in M. Desdoint's paper.

Trains of 300 tonnes, with 70-tonne, 4-coupled engine, showed a mean resistance of 4.4 lbs. per ton.

VELOCITY RESISTANCES.

The following grades were found to approximately equalize the velocities at various speeds, with short trains:

Miles per hour.	Grade per cent.	Equivalent, lbs. per ton.
0 to 18⅛	0 to 0.5	10
18⅛ to 37	0.5 to 1.0	10 to 20
37 to 50	1.0 to 1.5	20 to 30
50 to 62	1.5 to 2.0	30 to 40

See also par. 447.

comparison than the precise cross-section area) compare about as follows:

American, ... 10 × 14 ft. = 140 sq. ft.
European, ... 8 × 12 " = 96 "

656. When we further remember that the car-bodies of American cars are separated by over six feet from each other because of the platforms, and that the trucks are still more widely separated; and when we remember further that foreign engines have no cabs, and a smaller cross-section generally—the foreign evi-

TABLE **165.**

ENGINE HEAD-RESISTANCE AT HIGH SPEED.

[According to the formula $R = 0.83V^2$ (see foot-note to preceding table) in which $R =$ the TOTAL resistance of the engine.]

SPEED. MILES PER HOUR.	Total Head Resistance. Lbs.	Horse-Power.	Lbs. Per Ton of Train (313 Tons).
10.........	83	2.213	.266
20.........	332	17.71	1.06
30.........	747	59.77	2.38
40.........	1328	141.67	4.25
50.........	2075	276.70	6.64
60.	2988	478.20	9.58
70.........	4067	759.30	13.05

Since the resistance in pounds increases as the *square* of the speed, the horse-power demanded will necessarily increase as the *cube* of the speed. It takes a very powerful engine to maintain a speed of 70 miles per hour on a level for any distance, and no engine can do it long, with no train whatever behind it. As the horse-power corresponds very correctly to the conditions at this maximum speed it must necessarily correspond very correctly with the facts at the lower speeds. See end of par. 664.

dence below given (par. 660 *et seq.*) seems to rather support than disprove the resistances given by the formulæ summarized in Table 166 below, although nominally smaller.

657. It has therefore seemed best to use as the basis for all train-resistance computations in this volume the formula above referred to (par. 652), proposed by Mr. Wm. H. Searles in his "Field-Book," since this formula in a single simple equation seems to approximate very closely to what experiment indicates to be an ordinary working maximum for the resistance of trains of all classes, at all speeds, and with all forms and weight of cars. It is recommended, with justice, by Mr. Searles as accomplishing this end, in the following words:

"It is an empirical formula, based upon a careful investigation of all such records of experiments on the subject, several hundred in number, as have come under the author's notice, and is believed to give results agreeing closely with the average experience and practice of the present day. It is designed to give the resistances per ton for all trains, whether freight or passenger, and at any velocity, under ordinary circumstances. Accidental circumstances, such as the state of the weather, and the condition of the road-bed, rails, and rolling-stock, may largely modify the resistance, but these, of course, are not taken account of in the formula."

The formula (simplifying its form somewhat) is as follows for velocities in miles per hour:

Average resistance of entire train in lbs. per ton of 2240 lbs., for all weights in gross tons,

$$R = 5.4 + .006\,V^2 + \frac{.0006\,V^2\,(\text{wt. eng. and tender})^2}{\text{gross wt. of train}};$$

Average resistance of entire train in lbs. per net ton, for all weights in net tons,

$$R = 4.82 + .005357\,V^2 + \frac{.0004783\,V^2(\text{wt. eng. and tender})^2}{\text{gross wt. of train}}.$$

This formula, with a comparison of others below it, is tabulated in Table 166.

658. It will be seen that this formula gives the same result whether a given weight of train be made up of light empty box cars, weighing perhaps 9 tons each, or loaded coal cars weighing three or four times as much and exposing only one third or one half the area to air resistance,

TABLE 166.

TRAIN RESISTANCE ON A LEVEL AS AFFECTED BY VELOCITY.

Giving what may be considered as the ordinary working maximum, as computed from the general formula of WM. H. SEARLES, coinciding closely with the apparent indications of the most recent tests, but possibly as much as *one third too high* for the resistances at high speeds under favorable conditions (par. 655 *et seq.*).

For formulæ of resistances **for trains of flat cars,** *subtract* about .0012 from coefficient of V^2. For resistances and formulæ **per long ton,** *add* 12 per cent.

For resistances and formulæ **per long ton,** *add* 12 per cent.

Weight of cars taken at 25 long tons, 56,000 lbs. each, loaded.

Any of the formulæ compared on the following page give practically identical results, except that Mr Chanute's formulæ (extracted from the new edition of Haswell's "Pocket-Book"), although correct for the trains probably tested, viz.: passenger trains at high velocities and freight trains at low velocities, give the resistance of freight trains at high velocities at only ½ to ⅔ as much per ton as passenger trains.

TABLE 166.—*Continued.*

COMPARATIVE FORMULÆ.

All resistances in pounds per ton of 2000 lbs.

in other words, it attaches no weight whatever to atmospheric resistance and the form of the train. The writer's experiments (Fig. 163) indicate positively that this is more nearly true than is generally suspected, but in going to such an extreme the formula is unquestionably defective. It would seem also to be theoretically defective—or if not that, certainly to go a long way beyond experimental authority—in multiplying one important term of the equation by the square of the weight of engine. No theoretical justification for this is apparent. The constant for rolling-friction, 4.8 lbs. per ton, is also a little too high for loaded trains, although fair for a mean between loaded and empty.

But with all these minor imperfections the formula is certainly one of wonderfully exact application to a wide range of trains, from an engine running light to the longest freight trains, and at all speeds. The writer may be overmuch disposed to look on it with favor, since, as examination of Fig. 165, Appendix A, and Table 165 will show, it could hardly agree better with all the conclusions of his own tests, made in 1879, had it been based on them alone; yet the comparison given in and below Table 166 with the formulæ given by Mr. O. Chanute in Haswell's "Engineer's Pocket-Book" shows that it compares equally well with some other modern formulæ.*

A variety of further evidence as to the absolute amount of train resistance at high speed is given below:

659. The tests of Mr. J. W. Hill on an American freight train at slow speeds, given in Tables 146–7 and Fig. 115, check very closely with the formula. Mr. Hill's tests were on a freight train weighing 782.94 tons in all, with an engine and tender weighing 55.72 tons. The observed and computed resistances compare as follows:

Velocity in Miles Per Hour.	Resistance in Lbs. Per Ton. Observed.	Computed.
17.23	7.57	6.97
22.67	7.27	8.54
23.00	7.55	8.66

The observed resistances should be reduced 5 to 10 per cent for the internal friction of the locomotive. They indicate that the formula is substantially correct at slow speeds, but increases too fast with speed.

660. Mr. Stroudley's tests on a train weighing 335.7 tons of 2240 lbs. gross,

* The examples of the application of these formulæ to various trains given in the above "Pocket-Book" contain some serious errors which are liable to deceive.

with an engine and tender weighing 60.05 tons of 2240 lbs. (Fig. 123) should, according to Mr. Searle's formula, have had the following resistance:

$$R = 5.4 + .012445 V^2$$
$$= 5.4 + \frac{V^2}{80.35}.$$

For 40 miles per hour this gives 25.3 lbs. per ton, which amounts to 906 horse-power, whereas the average horse-power is recorded as only 529 horse-power, and the maximum shown by any diagram was 668; but then the draw-bar traction on the same train is given as an average of 4477 lbs., which at the average speed of 44.3 miles per hour foots up 528 horse-power (13.36 lbs. average traction) transmitted through the draw-bar *to the train alone*, excluding all engine and head resistance. If the latter bore anything like the ratio to the car resistance that it does in Fig. 165, the total resistance should have been fully up to what Mr. Searle's formula gives.

661. *The Engineer* (April 4, 1884) states it to be a figure "accepted by locomotive superintendents" that with a total train-load of 336 long tons the train resistance at 60 miles per hour is 40 lbs. per ton, which corresponds closely to Table 166.

662. In a French paper on the subject of train resistance and economy of grades* we have the following formulæ given, which appear to have been deduced from very carefully made tests:

"The resistance of an engine and tender is given by the formula

$$R = 3.3 + \frac{3.5E}{1000} + \left(\frac{V}{20}\right)^2,$$

in which

E = Indicated tractive force in kilogrammes,
R = Resistance per tonne in kilogrammes,
V = Velocity in kilometres per hour.

"For the train hauled we have

$$R = 2 + \frac{V}{40}."$$

For a speed of 80 kilos. per hour, which is very nearly 50 miles per hour, and calling 2 lbs. per ton = 1 kilo. per tonne, as it is almost exactly, we have from this formula for the train tested by Mr. Dudley (Tables 146–7):

	Per Ton.	Total.
For engine resistance...............	60 lbs.	3,780 lbs.
For train resistance................	8 "	2,000 "
Total (for 313 tons)...........	18.5 lbs.	5,780 lbs.

* "Notice sur les Prix de Revient de la Traction, et sur les Economies réalisées par l'Application de Diverses Modifications aux Machines Locomotives. Par M. Ricour, Ingénieur en Chef des Ponts et Chaussées," *Annales des P. et C.*, Sept., 1885.

This corresponds very closely to what we have just deduced (Table 164) from Mr. Dudley's tests.

663. Another French formula, based on the experiments referred to beneath Figs. 164–165, gives still lower results, indicating, at 50 miles per hour,

For engine, tender, and rear car..........	31.0 lbs. per ton.
For interposed cars	7.1 " "

It is stated in the same paper that at about 18.6 miles per hour the resistance is double, and at 31 miles per hour triple, what it is at 6 to 9 miles, and that "at still higher velocities the increase is rapid." This is far from true for American rolling-stock, and probably for any other, up to 30 or 40 miles per hour, and the exact figures given may be rejected as untenable, except that they may serve as cumulative evidence that the resistances at high speeds are not so great as many formulæ, including those of Table 166, give them, at least for European trains under favorable conditions.

664. A test was made in 1884, upon the Bound Brook route, between Philadelphia and New York, to ascertain the difference in the consumption of coal between an express train running on schedule time and the same train run at a very low speed, but otherwise under the same conditions, the same five cars and precisely similar engines being used. The trains ran in each case from Philadelphia to Bound Brook and back, a distance of 119 miles. The slow trip was made in 9 hours and 23 minutes, 4420 lbs. of coal being consumed. The train stopped at the same places as the regular express trains, the only unusual feature of the trip being the funereal pace, averaging a little over 12½ miles an hour.

The performances compared as follows:

	Speed.	Coal burned.	
Slow trip........	12½ m. per h.	4,420 lbs.	
Fast trip........	50± " "	6,725 "	
Difference...	37½ m. per h.	2,305 lbs.	= 34.2 per cent saved.

The engine and tender weighed 75 tons, and the five cars 126 tons.

According to D. K. Clark's formula, $R = \frac{V^2}{171} + 8$ (for gross tons), the comparative resistances at these speeds should have been about 31 to 13¼ lbs., or more than double, and this gives a much less rapid increase with speed than most modern formulæ. (See Fig. 163.) By Table 166 the difference should have been more than three to one. This appears to indicate very low velocity resistances. Coal consumption, however, is but a very vague guide to train resistance, it being quite certain that the power is developed more economically at the higher speeds. Still this test certainly tends to show that the resistances due to speed are not as great as supposed, as do also the facts presented beneath, Table 164, Figs. 164, 165, and the tests already referred to (par. 444) as

made on the Lake Shore & Michigan Southern Railway (*Transactions Am. Soc. C. E.*, Oct., 1876, p. 344, "Experiments and Tests," by P. H. Dudley), in which tests the conclusions reached were expressed as follows :

"We found that, with the long and heavy trains of 650 to 700 tons it required less fuel with the same engine (Mogul) to run trains at 18 to 20 miles per hour than it did at 10 or 12 miles per hour. The engine at the highest rate of speed, seems to produce its power more economically."

TABLE 167.

SPEED OF THE FASTEST TRAINS IN ENGLAND AND AMERICA.

[From Mr. E. B. Dorsey's paper on "English and American Railroads Compared," Trans. American Soc. C. E., 1885-6.]

English Railways.

LINE.	Termini.	Miles.	Time, including Stops.	Average Speed, incl. Stops.
			h. m.	
London & N. W	London to Liverpool.....	201.75	4 30	44.8
" "	" Glasgow......	406	10 00	40.6
" "	" Edinburgh ...	401	9 55	40.4
" "	" Holyhead.....	264	6 40	39.6
Great Northern.............	" Glasgow......	444	10 20	43
"	" York	188.25	3 55	48.1
"	" Edinburgh ...	397	9 00	44.1
Great Western..............	" Swansea......	216	6 00	36
"	" Bristol........	118.5	2 36	45.6
London, Br. & S. Coast......	" Brighton	50	1 05	46.15
London, Ch. & D.....	" Dover	76.5	1 47	42.6
Midland.....................	" Nottingham ..	125	2 30	50

American Railways.

LINE.	Termini.	Miles.	Time, including Stops.	Average Speed, incl. Stops.
N. Y., N. H. & H...........	New York to Boston.....	234	6 00	39
Pennsylvania................	Jersey City to Phila......	89	1 59	44.9
"	" Pittsburg..	443	11 45	37.7
"	" Chicago...	911	25 15	36.1
N. Y. Central & H. R.......	New York to Albany	143	3 30	40.9
" "	" Buffalo....	441	11 00	40.1
" "	" Chicago...	980	25 30	38.4
Central of New Jersey......	Jersey City to Phila......	90	2 00	45
Baltimore & Ohio...........	Baltimore to Washington	40	0 45	53.33

These runs are in every case *from terminus to terminus*, which makes a difference of 5 to 8 miles an hour from the speed obtained by selecting only the most favorable parts of the run. See summary on following page.

The aggregates of the preceding tables compare as follows:

12 English trains, averaging	$240\frac{3}{8}$	miles run at	43.33	miles per hour.
9 American " "	$374\frac{1}{8}$	" "	41.71	" "

Or, omitting the two long runs of over 900 miles from Chicago to New York:

7 American trains, averaging 214 miles run at 42.90 miles per hour.

While this table correctly indicates that the fastest trains in England and America make substantially the same time, the average speed of all trains is undoubtedly considerably higher in England, owing chiefly to the fact that there are almost no grade crossings or highway crossings, and in part to the shorter runs, which always justify and require higher speed for equal convenience.

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665. According to Table 165, the difference in the horse-power demanded to overcome *the engine resistances only* in the Bound Brook test just mentioned would have been:

Trip.	Time × Horse-power.	"Hour Horse-powers."
Slow, ...	9.4 hours × 5 H. P	= 47
Fast, ...	2.4 hours × 271.7 H. P.	= 652
Total difference in head resistance, . . .		605

The total difference in coal consumption being 2305 lbs., we have $\frac{2305}{605} =$ 3.62 lbs. as the coal burned per horse power per hour, without making any allowance for the increased car resistance due to speed on the one hand, or for the greater economy with which steam is used at high speed on the other hand. As 3.62 lbs. is about a fair rate of coal consumption under the circumstances (rather high), these two latter may have approximately balanced each other.

666. Table 167 shows the fastest regular trains in England and America, every train on the list probably reaching a speed of 60 miles per hour on short stretches of almost every run. The fastest trains do not haul over 125 tons to train, but even then they could not probably make the time they do if the resistances were quite as high as in Table 166. When all proper allowances are made, however, the facts do not necessarily imply any materially lower resistance.

ENGINE-FRICTION.

667. In computing train resistance it is not essential to assume any different rolling-friction for the engine than for the cars. The tender-friction should of course be the same, and the engine-truck friction substantially the same, while for the driving-wheel base we have only to

consider the rolling-friction between wheel and rail only, ***and not the journal-friction***, since the latter does not tax the adhesion (par. 608). The same is true of all the internal machinery-friction of every nature and kind ; so that, as we have plenty of steam-power in freight service, or can have by reducing the speed, and only lack tractive force in pounds, the machinery and driving-journal friction is of slight importance for freight service, whether much or little. For passenger service it may be of more importance, and it will at least be profitable to summarize the evidence as to its amount.

668. The locomotive is a simple machine, and the evidence does not make it probable that more than 5 to 8 per cent of its indicated power fails to reach the periphery of the drivers. Ten per cent is often allowed. In complicated low-pressure compound engines the machinery-friction is 10 to 15 per cent. In small stationary engines (Table 168) the loss ranges from 12 to 20 per cent.

In 16 x 24 American locomotives, the tests of John W. Hill (Tables 146–7) show that some 13 lbs. per ton of locomotive and tender was actually required to propel it without load at speeds of 17 to 23 miles per

Table 168.

Estimated Cost of Power and Efficiency of Stationary Engines.

[Abstracted from a careful and detailed paper by Charles E. Emery, Ph.D., M. Am. So. C. E., Trans. Am. So. C. E., November, 1883.]

H. P.	Kind.	Cost in Mass. 1874.	Loss per cent by Friction.	Indicated H. P.	Feed-Water, per I H. P.	Coal per I. H. P.	Evap. per lb. Coal.	Cost per H. P. 309 days.
5	Portable Upright......	$645	20	6.25	42	5.60	7.5	$176.46
10	" "	988	20	12.50	38	5.10	7.5	109.96
15	" "	1,487	18	18.29	36	4.80	7.5	90.14
20	" Horizontal...	1,981	15	23.53	34	4.25	8.	73.28
25	" " ...	2,441	14	29.07	32	4.00	8.	67.28
50	Stationary Non-cond'g.	5,331	12	56.82	27	3.27	8.25	52.15
100	Condensing Single.....	9,207	11	112.36	23	2.61	8.8	36.02
200	" "	16,785	10	220.99	22.2	2.52	8.8	28.64
300	" "	23,899	9.5	331.49	22.2	2.52	8.8	26.82
400	" "	29,958	9.5	441.99	22.2	2.52	8.8	26.01
500	" "	36,220	9.5	552.49	22.2	2.52	8 8	25.66

This table is carried out in the paper in much more detail, but the above are the most important data.

hour, whereas the average resistance of the train behind it, at the same speeds, was only some $6\frac{3}{4}$ lbs. per ton. Assuming that, owing to the greater weight on the locomotive drivers, the rolling-friction proper, between rail and wheel, was at least as much as the rolling and axle friction combined of the train behind it, we may divide up this 18 lbs. approximately as follows:

	Lbs. Per Ton.	Total Lbs.
Taxing adhesion: Rolling-friction, ...	7	392
" " Head and oscillatory resistance, . .	2	112
Not taxing adhesion: Friction of engine running light,	4	224
" " Assumed addition due to load, .	5	280
Total, ...	18	1,008
Actual average tractive pull (nearly $\frac{1}{7}$ load on drivers), . . .		6,250
Maximum tractive pull in ordinary work ($\frac{1}{4}$ weight on drivers),		11,200

This would indicate that when the engine is working fairly hard the internal friction consumes about 9 per cent of the indicated power, but it is almost certainly too high. When an engine is working light and running fast a much larger proportion of the energy developed, up to nearly $\frac{1}{6}$, would appear to be used up by internal friction, and no doubt is—a waste well worthy of attention, but not of that ruinously injurious character that an equal tax on the adhesion would be.

669. THE FRICTION OF THE SLIDE-VALVE is one of the chief sources of loss by machinery-friction; but by the rapid introduction of "balanced" slide-valves. or those which have the pressure excluded or counteracted on the top side of the slide-valve, this loss is being largely eliminated. The slide-valve exposes an area of from 70 to 100 sq. in., averaging perhaps 90 sq. in., to the steam-pressure in the steam-chest, which may be taken to average at least 100 lbs. per sq. in., giving some 9000 lbs. pressure. With good lubrication this pressure would create no great amount of friction, but with the imperfect lubrication which alone is possible, it is far more serious. The coefficient is probably in the neighborhood of 0.1 to 0.2 in ordinary working, causing a resistance to motion, in both steam-chests, of 900 to 1800 lbs. With 5-in. travel of valve and 50-in. drivers the slide-valve travels about $\frac{1}{16}$ as far as the engine, which would make this loss equivalent to $\frac{900 \text{ to } 1800}{16}$ = say, 55 to 110 lbs. of tractive resistance, amounting to something like 1 per cent of the ordinary work done, which in starting is no doubt often much more.

Direct experiments on the Boston & Albany road gave a resistance to motion of 2100 lbs. in starting under the worst conditions—full stroke with throttle wide open; while with the Richardson balanced slide-valve, which is one of the most approved, 325 lbs. sufficed. When once in motion it is prob-

able that the contrast is much less striking, but the saving in wear as well as resistance is so great that balanced slide-valves promise to be soon practically universal.

670. Otherwise than this it is difficult to account for any great loss by friction at any one part of the machinery. Therefore, since no difficulty is found in obtaining correspondingly favorable results with stationary engines of equal power and more complication, we may conclude with some certainty that 5 to 8 per cent of the indicated power represents the full extent of the loss by machinery-friction proper, in ordinary cases.

671. Tests at the works of Messrs. Schneider & Co., Creusot, reported by Mr. M. F. Delafield in a notable paper published in the *Annales des Mines* (and most other scientific journals of the world), 1885, made on a 22 × 44 in. Corliss engine, which could be worked either condensing or non-condensing, gave the following relation of indicated and effective power:

Condensing engines, effective H. P. = .902 I. H. P. — 16
Non-condensing " " " = .945 I. H. P. — 12

This, however, is not known to apply correctly to other than engines approximately similar to that tested, which developed 140 to 250 H. P. with about 60 revolutions per minute, according as it was condensing or non-condensing.

672. Tests purporting to give very high or low engine friction must be looked on with extreme scepticism. There is especial danger of error in interpreting the apparent results of such tests. Thus, tests of an apparently very accurate character by the Locomotive Superintendent of the Eastern Railway of France * show that of the total indicated horse-power only 42.5 and 41.6 per cent was delivered to the draw-bar, in two successive tests, out of which it was assumed that 34.2 and 35.6 per cent was consumed by the bare friction of the engine mechanism, after deducing the assumed resistance of the engine and tender considered as vehicles. The error lay in an insufficient allowance for the latter, and especially in an insufficient allowance for head resistance, which at high passenger speeds, such as that of the tests, consumes a large part of the power.

673. An investigation by the writer given in par. 128 shows that 20 lbs. × 6.5 lbs. per car gives the ordinary consumption in passenger service; indicating a very small loss by internal friction.

674. To get at the collective resistance of the bearings of a locomotive under steam, and to separate it into its constituent elements, Messrs. Vuillemin, Guebhard, and Dieudonné made some experiments, narrated in a work by Josef Grossmann,† showing the following results:

* *Engineering* and *Engineer*, 1885.

† "Die Schmiermittel und Lagermetalle für Locomotiven, Eisenbahnwagen, Schiffsmachinen, etc." Von Josef Grossmann, Ingenieur der österreichischen Nordwestbahn. Wiesbaden, C. W. Kreidel's' Verlag, 1885.

	Pounds Per Net Ton.		
	Non-coupled pass. engines.	4-coupled engines.	6-coupled engines.
Total resistance per ton of locomotive......	16.0	25.2	30.44
Resistance of cold engine (connecting-rod removed)...............................	6.0	10.44	12.30
Percentage of latter to total resistance.....	37.5 p. c.	41.5 p. c.	40.5 p. c.

These figures are for speeds of 17 to 21 miles per hour.

If now the collective resistance of the axle and parallel-rod bearings and of the valve-gear be deducted from the resistance of the *cold engine*, as above given, the remainder ought to give the resistance due to rolling-friction; and if this be deducted from the total resistance of the above table, the remainder should be, approximately, the total resistance of all bearings in the *engine at work*.

The axle-friction coefficient was assumed at 0.009 and the proportion of the diameter of axle-journal to that of the wheels at $\frac{1}{18}$, giving for the axle-friction $1\frac{1}{2}$ lbs. per ton weight of engine. The friction of the valve-gear of the cold engine was taken as 1 lb. per ton of engine, and the crank-pin friction for four-coupled engines at 0.2 lb. and for six-coupled engines at 0.4 lb. per engine ton. Adding together these resistances, and deducting them from the resistances of the cold engines without connecting-rods, the following table was obtained.

	Pounds Per Net Ton.		
	Non-coupled pass. engines.	4-coupled engines.	6-coupled engines.
Total resistances per ton of locomotive, as above	16.0	25.2	30.44
Resistance of rolling-friction per ton of locomotive................................	3.50	7.74	9.40
Percentage of last to the total............	21.87	30.71 p. c.	30 88 p. c.
Resistance of oiled parts (in steam) per ton of locomotive.	12.50	17.46	21.04
Percentage of last to the total............	78.13	69.29 p. c.	69.12 p. c.

These figures were assumed to show how large a portion of the engine resistances those of the oiled parts constitute, which do not tax adhesion.

The experimental evidence as to the comparative rolling and internal friction of coupled and uncoupled engines is interesting and possibly correct, but the exact figures given, as with all such single statements, must be received with much allowance.

With regard to the increased amounts of rolling friction indicated for four- and six-coupled engines, the author reasonably remarks that it is in accordance with what might be expected, since the coupled wheels, on account of their slight difference of form and of imperfections in the track, cannot roll as perfectly as the uncoupled ones, and must slip more or less.

675. The following record of some other French tests gives very different results: *

For determining engine resistance, the locomotive to be tested was set in motion at 4 or 5 miles per hour, and change of velocity determined by accurate apparatus, from which the following resistances were computed:

	Pounds Per Ton of Resistance.		
	Passenger engine, 3 axles, 2-coupled, 78-in. drivers, 52 tonnes.	Locomotive for mixed service, 3-coupled axles, 59-in. drivers, 48 tonnes.	Freight engine, 4-coupled axles, 50-in. drivers, 70 tonnes.
Engine in working order...	6.4	7.2	8.0
Eccentrics and connecting-rod disconnected.........	4.7	4.5	6.2
Difference	1.7	2.7	1.8
Coupling-rods also disconnected..................	4.7	4.4	6.2

In all these tests the effect of disconnecting the coupling-rods is inappreciable. The tender resistance was found to be only 5.0 to 5.6 lbs. per ton. All the above are the mean of a number of tests, not differing greatly in result. The following are from still larger averages:

	Resistance in Pounds Per Ton.				
	Drivers.	No. axles coupled.	Coned tread. Link-motion.	Cylindrical tread. Link-motion.	Cylindrical tread. Walchaërt's valve-gear.
Passenger engine..	78″	2	6.2	..	5.2
Mixed engine......	59″	3	7.2	7.2	...
Freight engine......	51½″	3	9.4	...	...
Freight engine......	50″	4	...	...	8.2

The tests measured the resistances between velocities of 2½ to 5 miles per hour. The resistances *include* machinery-friction, and the very low speed would tend to make the resistances considerably higher than at working speeds, notwithstanding which fact it would appear as if the results must certainly be too low.

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* "Application de la Méthode rationale aux Études dynamométriques. Par M. Desdouits, Ingénieur de la Marine, adjoint a l'Ingénieur en Chef du Matériel et de la Traction des Chemins de Fer de l'État," *Annales des Ponts et Chaussées*, Mai, 1886.

CHAPTER XIV.

THE EFFECT OF GRADES ON TRAIN-LOAD.

676. THE absolute effect of gradients to increase the load on the engine is constant and easily determined. Under the theory of the inclined plane (or rather under the general theory of the equilibrium of forces) any body *W*, Fig. 167, resting on such an inclined plane, is acted on by at

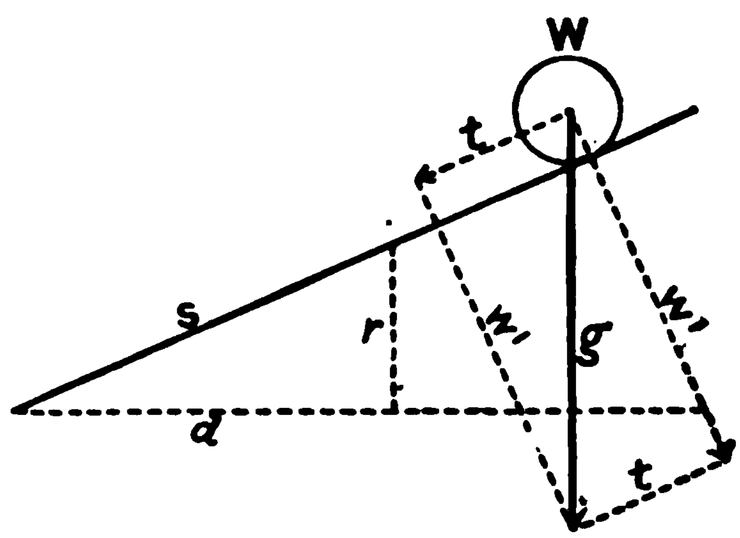

FIG. 167.

least two forces: the force of gravity, vertically downward; and the reaction of the supporting plane *s*, acting at right angles thereto.

Since a body acted on by two forces only cannot remain at rest (see any treatise on mechanics) unless the forces are (1) equal in magnitude, (2) opposite in direction to each other, and (3) lie in the same right line, motion must ensue under these conditions down the plane *s*; and the force *t* necessary to resist motion (or impelling the body down the plane, if equilibrium be not maintained) is represented by the length of any line *t*, which will suffice to close the triangle of forces. The direction of this force is ordinarily fixed by the conditions, and in the case we are now considering it must lie parallel with the plane *s*, as represented in the cut; but a force

acting in any other direction, as t' or t'', Fig. 168, will suffice for the same end, provided it will form with the forces g and w', Fig. 167, a closed triangle; the magnitude only of the force t required varying thereby.

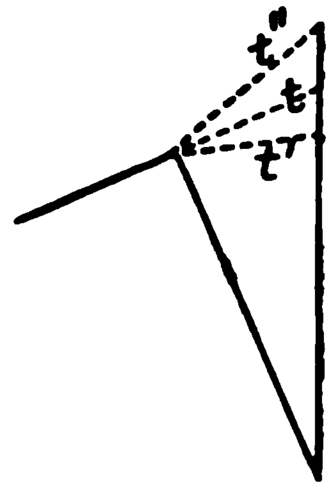

FIG. 168.

677. If the body W, Fig. 167, be an angular body, this necessary force t will be supplied by the friction of contact between the body and the plane, and the body will remain at rest until the angle becomes very considerable, as in sliding a brick down a board. If the body be a wheeled vehicle, the journal and other rolling-friction subserves the same purpose, so far as it goes, as respects motion down the plane; but since the rolling-friction is a very small portion of the total weight of the body, the angle of the slope on which the rolling-friction alone will suffice to maintain equilibrium must be very small. When it does not suffice for this purpose, the body is impelled down the plane by the *difference* between the force t of gravity and the retarding force of friction.

When a body is caused to move up the plane it is obvious that the resisting friction, whether much or little, plays no part in reducing the force t, tending to cause the body to move down the plane; for in that case the two forces resisting motion coincide with each other in direction, and their sum instead of their difference has to be overcome by the impelling force, whatever it may be.

678. These are the conditions under which the locomotive acts in hauling a train up a grade; and in Fig. 167, if g be made to represent the weight of any vehicle W or of all the vehicles, W' will represent the force with which they press against the rails; t, the "grade resistance" or force impelling them downward, or resisting motion upward; $\frac{t}{g}$, the ratio of the grade resistance to the weight; $\frac{2000t}{g}$ or $\frac{2240t}{g}$, according to the number of pounds in the ton, the grade resistance in pounds per ton; $\frac{W'}{g}$, the ratio of the reaction against the rails to the actual weight of the body, which may be deduced, for any grade, from Table 119, p. 341.

679. All grades are, in the technical work of American and Continental engineers, expressed in the rate per cent, although in common American practice the words "per cent" are (somewhat unfortunately) omitted, the grades being known as a 0.5, 0.8, or 1.0 grade. A grade so expressed is independent of the particular unit of measure employed, whether feet,

metres, miles, or any other. In popular American and English language grades are expressed by feet per mile, which (since there are 5280 feet in a mile) is 52.8 times the rate per cent. The use of this awkward unit, especially among engineers, is in every way to be regretted. English engineers are also much given to a still more awkward habit—expressing grades as rising "1 in 80," or some other horizontal distance. (See par. 683.) These may be turned into grades per cent with a table of reciprocals. In Fig. 167 the rate of grade is given by $\frac{r}{d}$. If we let $d = 100$ (whether feet or any other unit), then r will give, in the same unit, the rate per cent of the grade.

680. Since gravity, g, in the diagram of forces in Fig. 167, is represented by the hypothenuse of a right-angled triangle, it follows that the pressure of the wheels on the rails, W', can never be quite equal to the weight of the body. The loss, however, is not on any ordinary grade a serious or even an appreciable one. It may be determined as follows: Ratio of pressure on rails to real weight $\frac{W'}{g}$ (Fig. 167) $= \frac{d}{s}$; but $s = \sqrt{d^2 + r^2}$, exactly. Or, approximately (1),

$$s - r = \frac{r^2}{2d};$$

whence (2),

$$s = \frac{r^2}{2d} + d.$$

681. This latter is determined by a rule of great convenience, which is too little known, and which the student will do well to fix indelibly in his memory, for the multitudinous uses of which it is capable, viz.:

TO SOLVE A RIGHT-ANGLED TRIANGLE OF SMALL ALTITUDE: ***Square the height or rise and divide by twice the base or hypothenuse*** (whichever is known). The quotient will be the DIFFERENCE between the base and hypothenuse, whence the unknown side is obtained from the known by direct addition or subtraction. Frequently, however, in solving such triangles the difference only is required.

Examples showing the range of error in this rule are given in Table 168½. The extreme examples of the latter part of the table are intended only for illustrative purposes, but show that even in such an extreme case as the "3, 4, and 5 triangle" the error is only $\frac{1}{40}$ or 2½ per cent. For a multitude of engineering computations, where the altitude of the triangle is below ¼ the base, the formula is sufficiently approximate for all purposes, the error with base 4 and altitude 1 being less than half of one per cent and varying as the square of the altitude.

TABLE 168½.

EXAMPLES SHOWING RANGE OF ERROR IN THE APPROXIMATE FORMULA OF PAR. 681 FOR SOLVING RIGHT-ANGLED TRIANGLES.

GIVEN—		HYPOTHENUSE.		Error Per Cent.
Base.	Height.	By Approximate Rule.	Exact.	
10	1	10.05	10.049	0.01
10	2	10.2	10.198	0.02
10	4	10.8	10.770	0.03
10	5	11.25	11.180	0.6
10	6	11.8	11.662	1.2
10	8	13.2	12.806	3.0
10	10	15.0	14.142	5.7
4 (hyp.)	3	$5\frac{1}{8}$ (base.)	5.	$\frac{1}{40}$
5	3	$4\frac{1}{10}$	4.	$\frac{1}{40}$

All these examples are far beyond the range of the highest rates of grade. For examples of the latter, see Table 119, page 341.

682. Comparing the two similar triangles, *drs* and *W'tg*, Fig. 167, we have, since $r : d :: t : W'$,

$$t = \frac{W'r}{d},$$

W' being, as we have seen, not the true weight or gravity of the body, but the component thereof at right angles to the plane, or the force with which it presses against the plane.

On any grade practicable for locomotives, however, W' and g are practically equal to each other, the difference even on a 10 per cent grade being only one half of 1 per cent, and on a 1 per cent grade (52.8 feet per mile) only $\frac{1}{100}$ as much, or $\frac{1}{200}$ of 1 per cent. Therefore it is universally customary to consider that for all practical purposes $r : d :: t : g$, Fig. 167, whence

$$t = \frac{gr}{d}$$

with sufficient exactness, and we have the rule already given in par. 382: *The rate of grade in ft. per* 100 = *the grade resistance in lbs. per* 100 *lbs.*, whence, evidently,

THE GRADE RESISTANCE IN LBS. PER TON = the rate of grade per cent × 20, OR = 2 LBS. PER 0.1 PER CENT.

This last formula should likewise be indelibly engraven on the memory of the engineers having to do with railway work, making reference to a table needless.

683. The grade resistance in lbs. per ton on a grade given in feet per mile is $\left(\text{since the rate per cent} = \frac{\text{grade in feet per mile}}{52.80}\right)$ equal to the $\frac{\text{grade in feet per mile}}{52.80} \times 20 = \frac{\text{grade in feet per mile}}{2.64}$.

Or, since $\frac{1}{2.64} = 0.3788$, we have—

Grade resistance in lbs. per ton = grade in ft. per mile × 0.3788 = grade in ft. per mile ÷ 2.64.

For the long ton of 2240 lbs. we obtain, in the same way,

Grade resistance in lbs. per ton = grade in ft. per mile × $.4\dot{2}4\dot{2}$.

For a grade expressed in a horizontal distance for a rise of 1, as 1 in 80, 1 in 100, or 1 in d, the total grade resistance is $\frac{1}{80}$, $\frac{1}{100}$, or $\frac{1}{d}$ of the weight; or in lbs. per ton, $\frac{2000}{d}$ or $\frac{2240}{d}$, for the short and long ton respectively. This method of expressing grades is used nowhere in the world but by English engineers, and has nothing to commend it.

684. From the preceding it follows that the effect of grades UPON THE GRADE RESISTANCE is directly as the rate of grade. On a grade of 1.0 per cent, the grade resistance is just twice as much as on a grade of 0.5; and by whatever percentage the rate of grade be reduced the grade resistance will be reduced as much.

To determine the effect of the grade resistance ON THE POWER OF ENGINES, *the rolling-friction*, a constant element per ton on both grades and levels, must first be considered, in addition to the grade resistance.

685. Assuming, for reasons already stated (par. 623), that the rolling-friction at ordinary freight speeds of, say, 15 miles per hour is 8 lbs. per ton (= 0.4 per cent grade), which is a high resistance to assume, and much higher than the ordinary resistance of the train behind the engine only, the total train resistance, and hence gross weight of trains on any two rates of grade, will be as the rate of grade per cent + 0.4, or as

$$\frac{g + 0.4}{g' + 0.4}.$$

On grades of 0.5 and 1.0 per cent, adding 0.4 to each, we have 0.9 and 1.4 as the equivalent gradient in each case, including the rolling-friction.

The gross weight of trains on these grades, consequently, will be as 0.9 . 1.4 or 1 to 1.556, and not as 0.5 : 1.0 or 1 to 2.00.

With grades of 0.3 and 0.6 per cent, we have for the comparative gross weight of trains 0.7 : 1.0 or 1 to 1.43, instead of 1 to 2.00. With grades of 1.0 and 2.0 per cent we have, similarly, 1.4 : 2.4, or 1 to 1.714 for the comparative gross weight; whereas in this, as in the two former examples, the grade resistance only is as 1 to 2.

686. It will be seen from these examples that as the grades are higher the comparative gross weight of trains comes nearer and nearer to the ratio of the grade resistance only, as is but natural, since the rolling-friction becomes a less and less important fraction of the total resistance. Thus, in grades of 2.00 and 3.00 per cent, the comparative gross loads are as 2.4 : 3.4 or 2 : 2.833. But on the lower gradients this is far from being the case.

687. So far, we have considered only the gross weight of train, including engine; but it is apparent that the true measure of the cost of gradients is their effect upon THE NET OR REVENUE-EARNING LOAD of cars and freight, and the ratio of the NET loads on any two gradients depends upon an additional variable, viz., *the* RATIO *of the gross weight of engine and tender* (or rather, of engine, tender, and caboose) *to the tractive power of the engine.* Whatever the absolute weight of the engine, if its ratio to the tractive power be the same, the ratio of the net loads will be the same on any two given grades, whether the engine be light or heavy.

For the gross weight of train on any given grade is directly as the tractive power, and if the ratio of the weight of engine to the tractive power be the same, the resulting net loads, as well as gross loads, will be to each other directly as the tractive power.

688. The ratio of the tractive power to the total weight of engine is not a constant, but varies, *first*, with the pattern of engine, and, *secondly*, with the ratio of adhesion, which is itself a variable quantity; but assuming the constant ratio of adhesion of ONE FOURTH, which we have seen (par. 530) to be that justified by ordinary American experience, the ratio is readily determined for any pattern of engine, and will be seen from the following Table 169 to vary from 1 to 10½ to 1 to 4, according to the pattern of engine, the ratio for the more usual patterns of freight engines being about 1 to 7.

In the former edition of this treatise it was assumed as 1 to 10, the average ratio of adhesion being taken at ⅕, but conditions have greatly changed since then (1872-6).

TABLE 169.

RATIO OF WEIGHT OF ENGINE AND TENDER TO THE TRACTIVE POWER, FOR VARIOUS TYPES OF ENGINES,

As assumed in the headings of Table 170, substantially in accordance with the data of Tables 127–131.

KIND OF ENGINE.	Tractive Power. (¼ Weight on Drivers.)	Total Weight of Engine and Tender in Service.	Ratio of Weight to Tractive Power.
	tons.	tons.	trac. power = 1.0.
Light American	5	52	10.4
Average American	6	58	9.67
Light Ten-wheel	7	60	8.57
Average Ten-wheel Light Mogul	8	64	8.0
Average Mogul	9	67	7.44
Light Consolidation	10	70	7.0
Average "	11	75	6.82
St'nd (1887) "	12	80	6.67
Heavy Mastodon.........?...	13	87	6.69
Tank Consolidation	....	....	about 4.50
Tank Switch-engine (all weight on drivers)	....	....	4.00

If any one of these constant ratios be subtracted from the fourth column of the long Table 170, it will give a column of ratios of net loads to tractive power which, when multiplied by the tractive power of any engine whatever of the same proportion of weight on drivers to total weight, will give its hauling power.

689. From the preceding it will be clear that if we know merely the RATIO of the net load to the tractive power we can determine by what per cent a given increase or decrease of grade will modify the necessary tractive power, without determining the absolute amount of either the one or the other, and this method was followed in the first edition of this treatise. It obliges us to assume, however, that this ratio is constant; and as it is commonly the case that with every considerable variation in the weight of engine the ratio of its power to its weight will also vary, it is practically much better to study the effect of gradients, and of the changes therein, directly from a table showing the tons of net load, exclusive of engine, tender, and caboose, which various patterns of engine can handle on various grades. Such a table is given in the following long Table 170, in which the net load in tons for nine different patterns of engines, varying from light American to the heaviest Mastodon engines, is shown for every 0.02 per cent of grade up to 4.0 per cent, and from that to 10 per cent at wider intervals.

690. Table 170 is computed under the following assumptions:

Rolling-friction, ...	8 lbs. per ton.
Adhesion or tractive power, ...	¼ weight on drivers.
Weight of tender (about two-thirds loaded), as noted in the heading to the table, ...	21 to 25 tons.

It gives also, in addition to the grade per cent, the corresponding grade in feet per mile, the resistance in pounds per ton on each grade due to gravity only, and to gravity and rolling-friction (8 lbs.) combined, and the ratio of the gross load to the tractive power, or

$$\frac{2000}{\text{total resistance in lbs. per ton}}.$$

This ratio × *tons of tractive power* of each engine (= ¼ weight on drivers) = *gross* weight of train in tons which the engine can haul. Subtracting from it the total weight of each engine, as given in the first line of each heading, we have the net load of train in tons, as given in the nine columns which constitute the body of the table.

691. This Table 170 we shall make the basis of our ensuing study of the effect of gradients on net loads. Experience has clearly shown that only by the aid of such tables or by diagrams can the effect of gradients be comprehended, since the number of variables entering into such a table is so great that formulæ become very intricate in form, and carry no impression to the mind. The weight of the caboose at the rear of the train, which is practically only another tender, and almost universally used, might well have been included as a part of the gross weight of the engine and tender in Table 170; but there are two styles of caboose in use, 4-wheel and 8-wheel, differing considerably in weight, and for other reasons it seemed better not to include it.

692. In Table 138 a variety of records of actual performances of engines has already been given, which justify the claim made at the head of Table 170, that it represents the fair working capacities of the various engines on the given grades in good American practice. THE CAUTIONS AT THE HEAD AND FOOT OF THE TABLE MUST BE FULLY REMEMBERED, however, that the grades must be the *de-facto* or virtual grades, not increased in effect by unreduced curvature or by stops on or near the grade, nor decreased in effect by the assistance of momentum (see par. 413 *et al.*), either of which contingencies may make the nominal grades of the profile anything but the true governing gradients. Fig. 169 with its accompanying note will serve better than Table 170, perhaps, to make the effect of grades on train-load clear to the eye.

TABLE 170.

MAXIMUM WORKING LOADS FOR LOCOMOTIVES IN DAILY SERVICE (BEHIND THE TENDER) ON ANY GIVEN *de-facto* RATE OF GRADE, UNCOMPLICATED BY CURVATURE OR FLUCTUATIONS OF VELOCITY.

Adhesion ¼. Rolling friction, 8 lbs. Tons of end of table).

Ratio in fourth colu drivers = gross trac ich — wt. eng. and tender = net tractive

75	80	87
51	55	62
44	48	52
11.	**12.**	**13.**
onsolidations.		**Mast'n.**
(Light) Average. 20 × 24.	St'nd Heavy. 20 × 24.	Ex. H'y. 21 × 26, or 19 × 30.
2675	2920	3163
2544	2777	3008
2425	2647	2868
2316	2529	2739
2217	2420	2621
2125	2320	2513
2040	2228	2413
1962	2142	2320
1889	2063	2235
1821	1989	2154
1758	1920	2080
1699	1855	2010
1644	1795	1944
1590	1738	1883
1543	1685	1825
1496	1634	1770
1453	1587	1719
1412	1540	1670
1372	1499	1624
1335	1459	1580
1300	1420	1538

.40	21.120	16.0	125.00	573	692	815	936	1058	1180	1300	1420	1538
.42	22.176	16.4	121.95	558	674	794	912	1031	1149	1266	1383	1498
.44	23.232	16.8	119.05	543	656	773	888	1004	1120	1235	1349	1461
.46	24.288	17.2	116.28	529	640	754	866	980	1093	1204	1316	1425
.48	25.344	17.6	113.64	516	624	735	845	956	1066	1175	1284	1390
.50	26.400	18.0	111.11	504	609	718	825	933	1041	1147	1253	1357
.52	27.456	18.4	108.70	491	594	701	806	911	1017	1121	1224	1326
.54	28.512	18.8	106.38	480	580	685	787	890	994	1095	1197	1296
.56	29.568	19.2	104.17	469	567	669	769	871	972	1071	1170	1267
.58	30.624	19.6	102.04	458	554	654	752	851	950	1047	1144	1240
.60	31.680	20.0	100.00	448	542	640	736	833	930	1025	1120	1213
.62	32.736	20.4	98.04	438	530	626	720	815	910	1003	1096	1188
.64	33.792	20.8	96.15	429	519	613	705	798	891	983	1074	1163
.66	34.848	21.2	94.34	420	508	600	691	782	873	963	1052	1139
.68	35.904	21.6	92.59	411	498	588	677	766	856	943	1031	1117
.70	36.960	22.0	90.91	403	488	576	663	751	839	925	1011	1095
.72	38.016	22.4	89.29	394	478	565	650	737	823	907	991	1074
.74	39.072	22.8	87.72	387	468	554	638	712	807	890	973	1053
.76	40.128	23.2	86.21	379	459	543	626	709	792	873	955	1033
.78	41.184	23.6	84.75	372	450	533	614	696	777	857	937	1014
.80	42.240	24.0	83.33	365	442	523	603	683	763	842	920	996
.82	43.296	24.4	81.97	358	434	514	592	671	750	827	904	979
.84	44.352	24.8	80.65	351	426	505	581	659	736	812	888	961
.86	45.408	25.2	79.37	345	418	496	571	647	724	798	872	945
.88	46.464	25.6	78.13	339	411	487	561	636	711	784	858	929
.90	47.520	26.0	76.92	333	404	478	551	625	699	771	843	913
.92	48.576	26.4	75.76	327	397	470	542	615	688	758	829	898
.94	49.632	26.8	74.63	321	390	462	533	605	676	746	816	883
.96	50.688	27.2	73.53	316	383	455	524	595	665	734	802	869
.98	51.744	27.6	72.46	310	377	447	516	585	655	722	789	855
1.00	52.800	28.0	71.43	305	371	440	507	576	644	711	777	842
1.02	53.856	28.4	70.42	300	365	433	499	567	634	700	765	828
1.04	54.912	28.8	69.44	295	359	426	492	558	624	689	753	816
1.06	55.968	29.2	68.49	290	353	419	484	549	615	678	742	803
1.08	57.024	29.6	67.57	286	347	413	477	541	606	668	731	791
1.10	58.080	30.0	66.67	281	342	407	469	533	597	658	720	780
1.12	59.136	30.4	65.79	277	337	401	462	525	588	649	709	768
1.14	60.192	30.8	64.94	273	332	395	456	517	579	639	699	757
1.16	61.248	31.2	64.10	268	327	389	449	510	571	630	689	746
1.18	62.304	31.6	63.29	264	322	383	442	503	563	621	679	736
1.20	63.360	32.0	62.50	260	317	377	436	495	555	612	670	725

1.60	84.480	40.0	50.00	198	242	290	336	383	430	475	520	563
1.62	85.536	40.4	49.50	195	239	286	332	378	425	469	514	556
1.64	86.592	40.8	49.02	193	236	283	328	374	420	464	508	550
1.66	87.648	41.2	48.54	191	233	280	324	370	415	459	502	544
1.68	88.704	41.6	48.08	188	230	277	321	366	411	454	497	538
1.70	89.760	42.0	47.62	186	228	273	317	362	406	449	491	532
1.72	90.816	42.4	47.17	184	225	270	313	358	402	444	486	526
1.74	91.872	42.8	46.73	182	222	267	310	354	397	439	481	520
1.76	92.928	43.2	46.30	179	220	264	306	350	393	434	476	515
1.78	93.984	43.6	45.87	177	217	261	303	346	389	430	470	510
1.80	95.040	44.0	45.45	175	215	258	300	342	384	425	465	504
1.82	96.096	44.4	45.05	173	212	255	296	338	380	421	461	498
1.84	97.152	44.8	44.64	171	210	252	293	335	376	416	456	493
1.86	98.208	45.2	44.25	169	207	250	290	331	372	412	451	488
1.88	99.264	45.6	43.86	167	205	247	287	328	369	407	446	483
1.90	100.320	46.0	43.48	165	203	244	284	324	365	403	442	478
1.92	101.376	46.4	43.10	163	201	242	281	321	361	399	437	473
1.94	102.432	46.8	42.74	162	198	239	278	318	357	395	433	469
1.96	103.488	47.2	42.37	160	196	237	275	314	354	391	428	464
1.98	104.544	47.6	42.02	158	194	234	272	311	350	387	424	459
2.00	105.600	48.0	41.67	156	192	232	269	308	347	383	420	455
2.02	106.656	48.4	41.32	155	190	229	267	305	343	380	416	450
2.04	107.712	48.8	40.98	153	188	227	264	302	340	376	412	446
2.06	108.768	49.2	40.65	151	186	225	261	299	336	372	408	441
2.08	109.824	49.6	40.32	150	184	222	259	296	333	369	404	437
2.10	110.880	50.0	40.00	148	182	220	256	293	330	365	400	433
2.12	111.936	50.4	39.68	146	180	218	253	290	327	361	396	429
2.14	112.992	50.8	39.37	145	178	216	251	287	324	358	392	425
2.16	114.048	51.2	39.06	143	176	213	248	285	321	355	389	421
2.18	115.104	51.6	38.76	142	175	211	246	282	318	351	385	417
2.20	116.160	52.0	38.46	140	173	209	244	279	315	348	382	413
2.22	117.216	52.4	38.17	139	171	207	241	277	312	345	378	409
2.24	118.272	52.8	37.88	137	169	205	239	274	309	342	375	405
2.26	119.328	53.2	37.59	136	168	203	237	271	306	338	371	402
2.28	120.384	53.6	37.31	135	166	201	234	269	303	335	368	398
2.30	121.440	54.0	37.04	133	164	199	232	266	300	332	364	395
2.32	122.496	54.4	36.76	132	163	197	230	264	298	329	361	391
2.34	123.552	54.8	36.50	130	161	195	228	261	295	326	358	387
2.36	124.608	55.2	36.23	129	159	194	226	259	292	324	355	384
2.38	125.664	55.6	35.97	128	158	192	224	257	290	321	352	381
2.40	126.720	56.0	35.71	127	156	190	222	254	287	318	349	377

I. H. P. = 33,000 ft.-lbs. per min. = .1876 mile-tons (of trac. force) per hour

$$= \frac{1}{5.33}.$$

TABLE 170.—*Continued.*

MAXIMUM WORKING LOADS FOR LOCOMOTIVES IN DAILY SERVICE (BEHIND THE TENDER) ON ANY GIVEN *de-facto* RATE OF GRADE, UNCOMPLICATED BY CURVATURE OR FLUCTUATIONS OF VELOCITY.

Adhesion, ¼. Rolling friction, 8 lbs. Tons of 2000 lbs. (see note, end of table).

☞ *Ratio in fourth column × ¼ wt. on drivers = gross tractive power of any engine, which − wt. eng. and tender = net tractive power, behind tender.*

Tot. weight eng. and l'ded tender—tons				52	58	60	64	67	70	75	80	87
Weight engine only—tons				31	37	37	42 38	43	46	51	55	62
Weight on drivers—tons				20	24	28	32	36	40	44	48	52
Tons tractive power (¼ adh.)				**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**	**13.**
Rate of Grade.		Total Resistance, lbs. per net ton.	Ratio of gross w'gt of train to tractive power.	**American.**		**Moguls and 10-wheel.**			**Consolidations.**			**Mast'n.**
Per 100.	Feet per Mile.			Light. 14 × 24.	**Standard.** 17 × 24.	Light 10-wheel. 16 × 24.	Av. 10-wh 18 × 24. Lt. Mog. 17 × 24.	St'd 10-wh 19 × 24. Mogul. 18 × 24.	Light (P. R.R.). 20 × 24.	(Light) Average. 20 × 24.	St'nd Heavy. 20 × 24.	Ex. H'y. 21 × 26, or 19 × 30
2.40	126.720	56.0	35.71	127	156	190	222	254	287	318	349	377
2.42	127.776	56.4	35.46	125	155	188	220	252	285	315	346	374
2.44	128.832	56.8	35.21	124	153	186	218	250	282	312	343	371
2.46	129.888	57.2	34.97	123	152	185	216	248	280	310	340	368
2.48	130.944	57.6	34.72	122	150	183	214	245	277	307	337	364
2.50	132.000	58.0	34.48	120	149	181	212	243	275	304	334	361
2.52	133.056	58.4	34.25	119	147	180	210	241	272	302	331	358
2.54	134.112	58.8	34.01	118	146	178	208	239	270	299	328	355
2.56	135.168	59.2	33.78	117	145	176	206	237	268	297	325	352
2.58	136.224	59.6	33.56	116	143	175	204	235	266	294	323	349
2.60	137.280	60.0	33.33	115	142	173	203	233	263	292	320	346
2.62	138.336	60.4	33.11	114	141	172	201	231	261	289	317	343
2.64	139.392	60.8	32.89	112	139	170	199	229	259	287	315	341
2.66	140.448	61.2	32.68	111	138	169	197	227	257	284	312	338
2.68	141.504	61.6	32.47	110	137	167	196	225	255	282	310	335
2.70	142.560	62.0	32.26	109	136	166	194	223	253	280	307	332
2.72	143.616	62.4	32.05	108	134	164	192	221	250	278	305	330
2.74	144.672	62.8	31.85	107	133	163	191	220	248	275	302	327
2.76	145.728	63.2	31.65	106	132	162	189	218	246	273	300	324
2.78	146.784	63.6	31.45	105	131	160	188	216	244	271	297	322
2.80	147.840	64.0	31.25	104	129	159	186	214	242	269	295	319

2.80	147.840	64.0	31.25	104	129	159	186	214	242	269	295	319
2.82	148.896	64.4	31.06	103	128	157	184	213	241	267	293	317
2.84	149.952	64.8	30.86	102	127	156	183	211	239	264	290	314
2.86	151.008	65.2	30.67	101	126	155	181	209	237	262	288	312
2.88	152.064	65.6	30.49	100	125	153	180	207	235	260	286	309
2.90	153.120	66.0	30.30	99	124	152	178	206	233	258	284	307
2.92	154.176	66.4	30.12	99	123	151	177	204	231	256	281	305
2.94	155.232	66.8	29.94	98	122	150	176	202	229	254	279	302
2.96	156.288	67.2	29.76	97	121	148	174	201	228	252	277	300
2.98	157.344	67.6	29.59	96	120	147	173	199	226	250	275	298
3.00	158.400	68.0	29.41	95	118	146	171	198	224	249	273	295
3.05	161.04	69.0	28.99	93	116	143	168	194	220	244	268	290
3.10	163.68	70.0	28.57	91	113	140	165	190	216	239	263	284
3.15	166.32	71.0	28.17	89	111	137	161	187	212	235	258	279
3.20	168.96	72.0	27.78	87	109	134	158	183	208	231	253	274
3.25	171.60	73.0	27.40	85	106	132	155	180	204	226	249	269
3.30	174.24	74.0	27.03	83	104	129	152	176	200	222	244	264
3.35	176.88	75.0	26.67	81	102	127	149	173	197	218	240	260
3.40	179.52	76.0	26.32	80	100	124	147	170	193	215	236	255
3.45	182.16	77.0	25.97	78	98	122	144	167	190	211	232	251
3.50	184.80	78.0	25.64	76	96	119	141	164	186	207	228	246
3.55	187.44	79.0	25.32	75	94	117	139	161	183	204	224	242
3.60	190.08	80.0	25.00	73	92	115	136	158	180	200	220	238
3.65	192.72	81.0	24.69	71	90	113	134	155	177	197	216	234
3.70	195.36	82.0	24.39	70	88	111	131	153	174	193	213	230
3.75	198.00	83.0	24.10	68	87	109	129	150	171	190	209	226
3.80	200.64	84.0	23.81	67	85	107	126	147	168	187	206	223
3.85	203.28	85.0	23.53	66	83	105	124	145	165	184	202	219
3.90	205.92	86.0	23.26	64	82	103	122	142	163	181	199	215
3.95	208.56	87.0	22.99	63	80	101	120	140	160	178	196	212
4.00	211.20	88.0	22.73	62	78	99	118	138	157	175	193	208
4.05	213.84	89.0	22.47	60	77	97	116	135	155	172	190	205
4.10	216.48	90.0	22.22	59	75	96	114	133	152	169	187	202
4.15	219.12	91.0	21.98	58	74	94	112	131	150	167	184	199
4.20	221.76	92.0	21.74	57	72	92	110	129	147	164	181	196
4.25	224.40	93.0	21.51	56	71	91	108	127	145	162	178	193
4.30	227.04	94.0	21.28	54	70	89	106	125	143	159	175	190
4.35	229.68	95.0	21.05	53	68	87	104	122	140	157	173	187
4.40	232.32	96.0	20.83	52	67	86	103	120	138	154	170	184
4.45	234.96	97.0	20.62	51	66	84	101	119	136	152	167	181
4.50	237.60	98.0	20.41	50	64	83	99	117	134	150	165	178

TABLE 170.—*Continued.*

MAXIMUM WORKING LOADS FOR LOCOMOTIVES IN DAILY SERVICE (BEHIND THE TENDER) ON ANY GIVEN *de-facto* RATE OF GRADE, UNCOMPLICATED BY CURVATURE OR FLUCTUATIONS OF VELOCITY.

Adhesion, ¼. Rolling friction, 8 lbs. Tons of 2000 lbs. (see note, end of table).

☞ *Ratio in fourth column × ¼ wt. on drivers = gross tractive power of any engine, which − wt. eng. and tender = net tractive power, behind tender.*

Tot. weight eng. and l'ded tender—tons				52	58	60	64	67	70	75	80	87
Weight engine only—tons				31	37	37	42 38	43	46	51	55	62
Weight on drivers—tons.....				20	24	28	32	36	40	44	48	52
Tons tractive power (¼ adh.).........				**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**	**13.**
Rate of Grade.		Total Resistance, lbs. per net ton.	Ratio of gross w'gt of train to tractive power.	**American.**		**Moguls and 10-wheel.**			**Consolidations.**			**Mast'n.**
Per 100.	Feet per Mile.			Light. 14 × 24.	**Standard.** 17 × 24.	Light 10-wheel. 16 × 24.	Av. 10-wh 18 × 24. Lt. Mog. 17 × 24.	St'd 10-wh 19 × 24. Mogul. 18 × 24.	Light (P. R.R.). 20 × 24.	(Light) Average. 20 × 24.	St'nd Heavy. 20 × 24.	Ex. H'y. 21 × 26, or 19 × 30.
4.50	237.60	98.0	20.41	50	64	83	90	117	134	150	165	178
4.55	240.24	99.0	20.20	49	63	81	98	115	132	147	162	175
4.60	242 88	100.0	20.00	48	62	80	96	113	130	145	160	173
4.65	245.52	101.0	19.80	47	61	79	94	111	128	143	158	170
4.70	248.16	102.0	19.61	46	60	77	93	109	126	141	155	168
4.75	250.80	103.0	19.42	45	59	76	91	108	124	139	153	165
4.80	253.44	104.0	19.23	44	57	75	90	106	122	137	151	163
4.85	256.08	105.0	19.05	43	56	73	88	104	120	135	149	161
4.90	258.72	106.0	18.87	42	55	72	87	103	119	133	146	158
4.95	261.36	107.0	18.69	41	54	71	86	101	117	131	144	156
5.00	264.00	108.0	18.52	41	53	70	84	100	115	129	142	154
5.2	274.56	112.0	17.86	37	49	65	79	94	109	121	134	145
5.4	285.12	116.0	17.24	34	45	61	74	88	102	115	127	137
5.6	295.68	120.0	16.67	31	42	57	69	83	97	108	120	130
5.8	306.24	124.0	16.13	29	39	53	65	78	91	102	114	123
6.0	316.80	128.0	15.62	26	36	49	61	74	86	97	107	116
6.2	327.36	132.0	15.15	24	33	46	57	69	81	92	102	110
6.4	337.92	136.0	14.71	22	30	43	54	65	77	87	97	104
6.6	348.48	140.0	14.29	19	28	40	50	62	73	82	91	99
6.8	359.04	144.0	13.89	17	25	37	47	58	69	78	87	94
7.00	369.60	148.0	13.51	16	23	35	44	55	65	7[illegible]	8[illegible]	89

7.00	369.60	148.0	13.51	16	23	35	44	55	65	74	82	89
7.2	380.16	152.0	13.16	14	21	32	41	51	62	70	78	84
7.4	390.72	156.0	12.82	12	19	30	39	48	58	66	74	80
7.6	401.28	160.0	12.50	10	17	27	36	45	55	62	70	75
7.8	411.84	164.0	12.20	9	15	25	34	44	52	59	66	72
8.00	422.40	168.0	11.90	7	13	23	31	40	49	56	63	70
8.2	432.96	172.0	11.63	6	12	21	29	38	46	53	60	64
8.4	443.52	176.0	11.36	5	10	20	27	35	44	50	56	61
8.6	454.08	180.0	11.11	4	9	18	25	33	41	47	53	57
8.8	464.64	184.0	10.87	2	7	16	23	31	39	45	50	54
9.00	475.20	188.0	10.64	1	6	14	21	29	36	42	48	51
9.2	485.76	192.0	10.42	0	5	13	19	27	34	40	45	48
9.4	496.32	196.0	10.20	....	3	11	18	25	32	37	42	46
9.6	506.88	200.0	10.00	....	2	10	16	23	30	35	40	43
9.8	517.44	204.0	9.80	....	1	9	14	21	28	33	38	40
10.00	528.00	208.0	9.62	....	0	7	13	20	26	31	35	38

Believed to be correct to nearest ton for ¼ adhesion and 8 *lbs. rolling-friction* on tangents, even half-tons being dropped.

Applicable to either long or short tons, or any other unit, if the weights of engine be supposed to be given in the same unit. The table gives simply, in effect, the *ratio* of net load behind engine to the total adhesion, assumed at ¼ the weight on drivers, × each even ton of adhesion, or each 4 tons on drivers. *Intermediate weights can be interpolated* by inspection. Adding total weight (as assumed) of engine and tender, as given in the heading, gives the gross weight *of engine and train* which an engine of any pattern whatsoever can take up any grade with ¼ adhesion. *For ⅓ adhesion* the gross load will be 33⅓ per cent greater, and *for ⅕ adhesion* 20 per cent less. The net load varies slightly with the pattern of engine. *For tank engines* having any given weight on drivers, correct the table by the difference between its actual weight in service, and that assumed for an engine with tender, with same load on drivers, in preparing this table.

The above table gives the fair working capacity for locomotives in everyday service on *de-facto* grades of the given rate, as shown by the daily practice of many lines (see Table 138). In *single tests* they will run some 20 per cent higher; in winter weather, about 10 per cent lower. Otherwise any considerable excess in reported loads above the preceding table indicates simply that the grades are not in reality as high as reported, but are probably operated as momentum grades; and any considerable deficiency indicates either carelessness in loading engines to their capacity or that the profile grades are in effect increased by unreduced curvature or by stopping-points on the maximum grade. Thus, a *de-facto* level grade for operating purposes hardly exists in the world; nor can it, except with a very unequal tra[illegible]bling all curves and stations to be on a descending grade, without impeding up traffic.

Net Train Load in Tons behind Tender

Fig. [illegible]. Effect of Grades on Net Train-Load.

[This diagram is reduced from one prepared by Mr. [illegible], Supt. M. P., No. Pacific Ry., with certain lines added. It is somewhat confusing on first examination, from the fact that it is not constructed according to established geometric methods, with a common origin for the two coordinate axes at their intersection O. It can best be studied by regarding the line at the bottom of the page as the horizontal axis [illegible], and regarding the curves as indicating the increase of net load from progressive diminutions of grade resistance. It is explained further on the opposite page.]

NOTES TO FIG. 169.

Regarding the bottom of the page as the base-line of the diagram, or axis of x, as explained beneath the title to it:

1. *The lower heavy line* represents the progressive increase of train-load (behind tender) as the grade is reduced, for the *lightest American engine* given in Table 170, which begins at 0 at a grade of 480 ft. per mile, and ends at 1198 tons on a level, just beyond the limits of the diagram.

2. *The upper heavy line*, marked **A**, represents the same thing for the *heaviest Mastodon engine* given in Table 170, so nearly that it is not in error by more than its own width at any point. It was not plotted for that purpose, however, but was one of the lines of the original diagram, as below, made blacker to correspond with line 1.

Similar lines for all the other nine engines whose tractive capacities are given in Table 170 would fall between these two lines at approximately regular intervals. It has not seemed necessary to plot them.

The remaining lines of the diagram give the cylinder and adhesion tractive powers separately for the three different engines below detailed, as computed by Mr. G. W. CUSHING, Supt. M. P. No. Pac. Ry., on the following assumptions:

Rolling-friction, 6½ lbs. per ton in place of 8 lbs. per ton, as in this volume.

Ratio of adhesion, ¼, as in this volume.

The difference in the rolling-friction makes the train-loads somewhat greater than those given in Table 170, especially as a level is approached, but makes no great difference on the higher grades. The three engines are as follows:

ENGINE.	Cylinders.	Drivers.	Trac. Pr. in Lbs., Per Lb. of Effective Pressure.	No. Drivers.	WEIGHTS. On Drivers.	Total Engine.	Tender, Loaded.	Total.
A	22" × 26"	49"	256.8	8	100,000	112,000	65,000	177,000
B	22" × 26"	49"	256.8	10	110,000	112,000	65,000	177,000
C	20" × 24"	49"	196	8	96,000	108,000	65,000	173,000

The lines marked **A**, **B**, **C** indicate the loads corresponding to the ADHESION tractive power of these three engines, computed on the basis of one fourth the weight on drivers.

The remaining lines indicate the CYLINDER tractive powers for the same engines at various points of cut-offs, as follows:

Engine **C**, 20" × 24", Consolidation, 48 tons on drivers. At half-stroke the cylinder power is somewhat less than the adhesion, and at 70 per cent very slightly over. Only at very slow speed can such an engine furnish steam for running at 70 per cent cut-off.

Engine **A**, 22" × 26", Consolidation, 50 tons on drivers, or 5 tons less than **B**, but identical in cylinder capacity, showing that the latter is in excess.

Engine **B**, 22" × 26", Mastodon, 55 tons on drivers. The two lines for cylinder tractive power apply alike to engines **A** and **B**. In both of these engines the cylinder power is much greater in proportion than in engine **C**, and cannot be fully utilized at one fourth adhesion. As the working adhesion on a good rail often rises much higher than one fourth

THE PERCENTAGE OF CHANGE IN THE NET LOAD RESULTING FROM A CHANGE IN THE RATE OF ANY GRADE.

693. Assuming Table 170 as a basis, we can readily determine from it, in the manner below outlined, the two following laws, which are the foundation for a correct estimate of the value of reducing grade:

First. *When the rate of any one given ruling grade is increased or decreased, the corresponding* PERCENTAGE *of increase or decrease in the engine-mileage required to handle any given tonnage varies almost directly as the change in rate of grade, however much or little the change may be, slightly increasing, however, as the increase is greater and decreasing as the decrease is greater.*

For example, if a 0.6 per cent grade be increased to 0.8 the increase in engine-tonnage required is, for Consolidation engines, $\frac{1025}{843} = 21.73$ per cent increase, or 10.9 per cent per 0.1 per cent of grade; but if it be increased to 1.5 per cent, the increase is $\frac{1025}{804} = 103.37$ per cent increase, or 11.48 per cent per 0.1 per cent of grade; being about $5\frac{1}{4}$ per cent more per 0.1 per cent of grade than for the smaller increase.

If the entire weight of the engine be considered a part the train, this law is exact, regardless of the actual weight of the engine, and the engine-tonnage varies PRECISELY with the change in rate of grade, as may be seen in Table 172.

Second. *The* AMOUNT *of this percentage of increase or decrease in*

---

however, this surplus cylinder power is likely to be very useful in handling heavy trains easily, and indicates that engine **B** at least is better designed than engine **C** for the most efficient freight service.

Where and why tank engines are advantageous may be very clearly seen from this diagram as follows:

Referring to the head-lines to Table 170, it will be seen that the TOTAL weight of the lightest American engine and the WEIGHT ON DRIVERS of the heaviest Mastodon are the same, 52 tons. A tank engine of the same total weight, all of it on drivers, while it will be a much lighter and cheaper machine than the Mastodon, and be equal to much lower speeds only, will have a greater net tractive power on all grades by the constant amount of 35 tons (saved in dispensing with a tender and leading truck). Therefore, plotting on Fig. 169 a line for 35 tons greater loads than for the upper heavy black line, we find that on the higher grades it makes an enormous difference in the percentage of net load hauled, but as the lower grades, below 2 per cent (106 ft. per mile), are reached the two lines become almost coincident.

the engine-tonnage required varies considerably with each grade, being nearly five times as much on a level as on a 3 per cent grade; and is about as given in the following Table 171, where these percentages are given for all grades, determined in a manner we will shortly review.

964. These two facts being definitely ascertained, we have, in order to determine the effect of any change of grade upon the engine-mileage required to handle a fixed tonnage, simply to multiply the percentage given in Table 171 (which see) by the number of *tenths per cent change of grade* to obtain the total increase in engine-mileage which will be required for any given change of grade; or, the same fact may be still better determined directly from the actual load on each grade, given in Table 170. This percentage, multiplied by the proportion of the expenses which varies with the number of trains or engine-tonnage (the car-mileage and traffic remaining constant), i.e., by the portion of the expenses which would be doubled if the engine-tonnage were doubled, will give the annual cost of a proposed increase of grade, or the annual saving of a proposed decrease.

695. Table 171 (see p. 556) is determined from Table 170 in the following simple manner:

Taking only three types of engines, the lightest "American," heaviest Consolidation, and any engine of the same weight on drivers as the latter, but counted as part of the train, and comparing the net loads given for grades of Level, 0.5, 1.0, 1.5, and 2.0 per cent, we have the following net loads hauled:

	Grades of				
	Level.	0.5.	1.0.	1.5.	2.0.
Light American, ...	1198	504	305	211	156
St'nd Consolidation, . .	2920	1253	777	552	420
Heavy eng. incl'd in train,	3000	1333	857	632	500

Then it is evident that, whatever the total tonnage to be moved, the percentage of increase in the engine-mileage required to move it will be, with a 1.5 per cent instead of 1.0 per cent ruling grade,

American.	Consolidation.	Engine incl'd with train.
$\frac{305}{211} = 1.446,$	$\frac{777}{552 -} = 1.408,$	$\frac{857}{632 -} = 1.357,$

times that required on a 1 per cent grade, or

44.55 per cent,	40.8 per cent,	35.7 per cent,

TABLE 171.

PERCENTAGE OF INCREASE (OR DECREASE) IN THE ENGINE-MILEAGE REQUIRED WHICH RESULTS FROM ANY CHANGE IN THE RATE OF ANY GRADE.

[Deduced from the long Table 170 in the manner explained in Table 172.]

INCREASE Per Cent in Engine-Mileage **Per 0.1 of Change in Grade** resulting from a Total Change of—				**Grade to be Changed**	**DECREASE** Per Cent in Engine-Mileage **Per 0.1 of Change in Grade** resulting from a Total Change of—			
79.2	52.8	26.4	5.28	Ft. Per Mile.	5.28	26.4	52.8	79.2
+ 1.5	**+ 1.0**	**+ 0.5**	**+ 0.1**	Per cent.	**− 0.1**	**− 0.5**	**− 1.0**	**− 1.5**
28.68	27.62	26.64	25.9	Level.	....	....	....	...
23.16	22.30	21.46	20.9	**.10**	20.6	....	....	....
19.43	18.73	18.02	17.5	**.20**	17.3	....	....	....
16.80	16.15	15.54	15.1	**.30**	14.9	...	....	....
14.84	14.25	13.72	13.3	**.40**	13.1	....	....	....
13.30	12.76	12.26	11.9	**.50**	11.8	11.42	....	....
12.05	11.58	11.16	10.8	**.60**	10.6	10.36	....	....
11.05	10.60	10.22	9.8	**.70**	9.7	9.48	....	....
10.24	9.81	9.44	9.2	**.80**	9.0	8.74	....	....
9.50	9.13	8.76	8.5	**.90**	8.4	8.14	....	....
8.93	8.56	8.22	8.1	**1.00**	7.8	7.60	7.34	....
7.91	7.59	7.26	7.0	**1.20**	6.9	6.76	6.52	....
7.18	6.86	6.60	6.3	**1.40**	6.3	6.10	5.88	....
6.58	6.27	6.02	5.8	**1.60**	5.8	5.56	5.37	5.17
6.09	5.80	5.60	5.5	**1.80**	5.4	5.14	4.95	4.77
5.67	5.38	5.20	5.1	**2.00**	5.0	4.80	4.62	4.44
5.35	5.01	4.86	4.8	**2.20**	4.7	4.50	4.31	4.14
5.05	4.79	4.66	4.6	**2.40**	4.4	4.22	4.07	3.92
4.85	4.58	4.44	4.4	**2.60**	4.2	4.00	3.85	3.71
4.68	4.39	4.24	4.2	**2.80**	4.0	3.80	3.67	3.55
4.50	4.23	4.06	4.0	**3.00**	3.8	3.62	3.50	3.37
4.03	3.80	3.66	3.6	**3.50**	3.5	3.38	3.19	3.07
3.79	3.57	3.34	3.4	**4.00**	3.3	3.10	2.97	2.83
3.51	3.30	3.14	3.2	**5.00**	3.0	2.80	2.63	2.51

These percentages are computed for an average Consolidation, having 11 tons tractive power or 88,000 lbs. on drivers, but they are substantially the same for all freight engines. See par. 698.

By interpolation any desired percentage can be determined from the above very approximately. Thus for an increase of 0.75 in a 0.75 grade we have

$$\frac{10.41 + 9.63}{2} = 10.02 \times 7.5 = 75 + \text{ per cent increase in engine-mileage.}$$

Exactly, it is (Table 170) $\frac{964}{552} = 74.64$ per cent. increase.

total increase of engine-mileage, equivalent to an average increase *per* 0.1 *of increase of grade* of

8.91 per cent, 8.16 per cent, 7.14 per cent.

For an increase from a 1.0 per cent to a 2.0 per cent, we have

American.	Consolidation.	Eng. incl'd with train.
$\frac{305}{156} = 1.955$,	$\frac{777}{420} = 1.850$,	$\frac{857}{500} = 1.714$,

a total increase per cent ot

95.5 per cent, 85.0 per cent, 71.4 per cent,

or an increase per 0.1 per cent of increase of grade of

9.55 per cent, 8.50 per cent, 7.14 per cent.

696. Proceeding similarly for other changes of grade, viz., 0.1, 0.3, 0.5, and 1.0 per cent of increase from a 1 per cent grade (making the maximum change considered, from a 1.0 per cent to a 2.0 per cent), and computing also the comparative engine-tonnage required for corresponding decrease in a 1 per cent grade, this extreme reduction being to Level, we obtain the following Table 172, in which the computations in the last

Table 172.

Showing the Effect of Various Changes in a One Per Cent Grade on the Engine Tonnage required for Three Patterns of Engines.

For a *Decrease* in a 1.00 Per Cent Grade of—	Making the Grade	The Per Cent of Change in Engine Tonnage needed is—			And the same Per 0.1 Per Cent of Change in Grade is—		
		Light American	Heavy Cons'n.	Eng. inc. with Train.	Light American.	Heavy Cons'n.	Eng. inc. with Train.
1.0 per cent.........	*Level.*	74.5	73.4	71.4	7.45	7.34	7.14
0.7 " "	0.3	53.9	52.4	50.0	7.70	7.49	7.14
0.5 " "	0.5	39.5	38.0	35.7	7.90	7.60	7.14
0.3 " "	0.7	24.3	23.1	21.4	8.11	7.71	7.14
0.1 " "	0.9	8.4	8.8	7.14	8.41	7.83	7.14
And for an *Increase* of.................	1.00	—	—	—	—	—	—
0.1 per cent.........	1.1	8.5	7.9	7.14	8.53	7.92	7.14
0.3 " "	1.3	26.0	24.1	21.4	8.68	8.04	7.14
0.5 " "	1.5	44.6	40.8	35.7	8.91	8.16	7.14
0.7 " "	1.7	64.0	58.2	50.0	9.14	8.31	7.14
1.0 " "	2.0	95.5	85.0	71.4	9.55	8.50	7.14

Computed from Table 170 in the manner explained in par. 695. The results of similar computations for all rates of grade are condensed in Table 171.

column but one correspond substantially with ONE LINE (that for a 1.0 grade) of Table 171. All the other lines of Table 171 were computed in the same way from Table 170, the figures only differing.

697. It will be seen in Table 172 that if we deal only with gross train loads we get exactly the same per cent of change in motive-power per unit of change of grade, whether it be great or small. In proportion as the dead weight of the engine becomes a larger proportion of the weight on drivers, the absolute per cent of change in motive-power increases, and likewise the irregularity of the percentage.

698. By interpolation in Table 171, the percentage for almost any kind of a change of grade can be readily determined. These percentages do not vary to any important extent with the pattern of engine, within the range likely to be used for freight service, nor even for considerable differences in the assumed ratio of adhesion. Moreover, as it is now well established that ¼ is the proper ratio to assume, for American practice at least, no other should be assumed.

699. Ordinarily the changes of grade which the engineer is called upon to consider are not very great. The typical percentage for any ordinary change in any grade, for use in estimating the value of a reduction or the cost of an increase, may therefore be taken to be that due to a change of 0.1 per cent in it, as shown in Table 178, which is practically the same for either an increase or a decrease of grade. For extreme differences of conditions, of any kind, the actual percentage of change in engine-tonnage should be directly computed from the relative train-loads given in Table 170.

We are now prepared to consider the cost of changing the hauling power of engines by changes of grades.

700. Table 173 will illustrate how enormously the virtual gradient as well as the work of the engine may be increased by frequent stops and quick starts. On the New York Elevated Railway the stops are so close together that it is absolutely essential that speed should be gotten up very quickly indeed if reasonably fast time is to be made. Accordingly we find that the work done in getting up speed is equivalent to an addition to the actual grade of 2.63 per cent, or 139 feet per mile—an addition so great that whether the actual grade be 1 per cent up or 1 per cent down makes comparatively little difference in the working of the engine. Table 173 gives an extreme example of conditions which obtain very largely in passenger service, and which make frequent stops a very serious disadvantage. Due allowance for this effect should never be forgotten in attempting to determine what the actual grades are.

TABLE 173.

HANDLING OF TRAINS ON MANHATTAN (ELEVATED) RAILWAY (THIRD AVENUE LINE).

[From a paper by Mr. Frank J. Sprague before the Boston Society of Arts, 1886.]

Length of line	8.48 miles.
Total lift, up track	144.42 ft.
Lineal distance for same	13,160 ft.
Total lift, down track	137.60 ft.
Lineal distance of same	16,510 ft.
Level on each track	15,100 ft.
Number of stations	27
Number of stoppages	26
AVERAGE TIMES:	
Single trip	42 min.
Per station	97 sec.
Under way	80 "
Stop	17 "
Time due to a run without stop at max. speed of 19.2 m. per hour	26.56 min.
Total time standing still at stations, at 17 sec. each	7.37 "
Time lost in slowing up and getting under way	8.07 "
Total	42.00 min.

Average distance between stations	1,722 ft.
DIVIDED NEARLY AS FOLLOWS:	
Getting up to 10 miles per hour	130 ft.
Thence to full speed (19.2 miles per hour)	495 ft.
Full speed	808 ft.
Slowing to stop	289 ft.
AVERAGE SPEED—miles per hour:	
Getting under way	13.4
Full speed	19.2
Slowing to stop	9.6
Mean between stations	12.1
DAILY WORK OF ONE ENGINE:	
Round trips made	9
Coal used	5,760 lbs.
Hours on duty	20
Hours using steam	6
Av. consumption of coal per trip	640 lbs.
Total horse-power per round trip	6,184
Horse-power per pound of coal $\frac{6184}{640} =$	9.66
Pounds of coal per H. P. p. h. $\frac{60}{9.66} =$	6.21

For a speed in miles per hour of	10.0	19.2
The velocity-head (Table 118) is	3.55 ft.	13.10 ft.
Divided by distance to acquire that speed	135 ft.	495 ft.
Gives as the virtual gradient due to that acceleration, in excess of the actual grade	2.63 p. c.	2.64 p. c.
If the actual grade be 1 per cent up, the same speeds will be acquired in a distance of	218 ft.	800 ft.
Or if 1 per cent down, in	98 ft.	360 ft.

Even so extreme a difference in grade makes comparatively little difference, therefore, in practical operation.

Getting up speed to 19.2 miles an hour 26 times is equivalent to lifting the train vertically $13.10 \times 26 = 340.6$ ft. in a run of 8.5 miles, or 40 ft. per mile, whereas the total tractive resistance in motion at that speed, at 10 lbs. per ton, is equivalent to some 26 ft. per mile only.

CHAPTER XV.

THE EFFECT OF TRAIN-LOAD ON OPERATING EXPENSES.

701. The increase in train resistance which results from an increase of ruling grade can be, and is, overcome in either of two ways: (1) By an increase in the weight and power of engines; (2) by decreasing the weight and increasing the number of trains.

The first of these—increasing the weight of engines—is by much the cheaper, but is only possible to a limited extent and under special circumstances. Ordinarily, it is not fair to assume that heavier engines are used on one alternate grade than on another, because, whatever advantage may be gained by using heavier engines on one grade may be equally well gained on the other grade. It is far more frequently possible to fairly assume the use of heavier engines on heavier grades with passenger than with freight service, but passing (until par. 732) the question of when it is or is not possible to adopt the cheaper expedient, we will estimate the cost of each separately.

THE COST OF INCREASING THE WEIGHT OF ENGINES.

702. The following items will not be increased at all by an increase of weight of engines to suit the requirements of a higher grade, the weight of train remaining the same: The cost of (1) repairs of cars; (2) train-wages; (3) general expenses; (4) maintenance of way and works, exclusive of rail and tie renewals and lining and surfacing; (5) *that portion* of the maintenance-of-way expenses last excepted which is caused by the cars and not by the engines.

The most reasonable estimate which can now be made of the relative effect of engine and cars upon the track is (pars. 115, 116) that considerably over half of the deterioration of track comes from the passage of engines over it, and the remainder only from the passage of cars, which may weigh ten or twenty times as much. Assuming one half only, we are led

to the conclusion (see Table 175) that more than three quarters of the total expenditure is unaffected by an increase of the weight of engines in any visible and direct way.

703. The effect on COST OF MAINTENANCE OF TRACK of increasing the weight of engines has been greatly modified and much reduced since the publication of the first edition of this volume (prepared, as it necessarily was, from records which were some years old in 1876) by the now universal use of steel rails in place of iron. The causes and extent of the changes thus brought about have been already summarized in par. 109 *et seq.* The most important of all, as respects the use of heavy engines, is that the nature of the wear of rails has changed. With iron rails, the wear took the form of a crushing or lamination, which destroyed their surface long before the direct abrasion had become a serious matter. This crushing was very greatly hastened by heavy loads per wheel, and increased in much faster ratio—to the extent that iron rails which would sustain the passage of light engines for many years would be crushed out by heavy engines in a few months. On the other hand, with steel rails (excluding those of inferior quality, of which far too many have been and are laid) the wear is merely direct abrasion, which is not materially increased per ton of train either by load per wheel or speed. As respects the last at least, there is very good reason to believe that it increases in much less than direct ratio.

704. For, as respects speed, when the question is one merely of abrasion and not of destruction impact, the less the TIME to which the rail is exposed to load the less, undoubtedly, the normal crushing effect, for the same reason that journal and other (i.e., brake) friction is less at high speeds or that it takes more force to rupture a specimen in a testing-machine quickly than slowly. Impacts proper play their part, no doubt, in the wear of steel rails as of iron rails, but so long as the

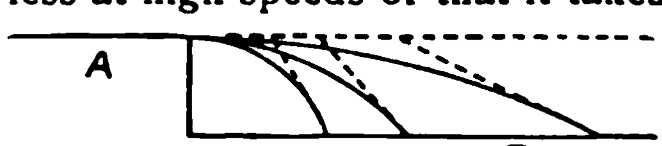

FIG. 170.

surface remains tolerably good (as it does almost indefinitely with the best steel rails) it is a small part. When the surface becomes seriously impaired steel rails go almost as quickly as iron; but either with steel or iron the effect of the impacts is not, as is often assumed, as Mv^2. This is true of a body impinging directly upon another; but one caused to impinge

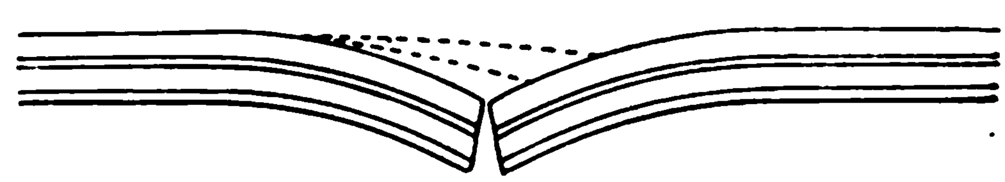

FIG. 171.

upon another in jumping from A to B under conditions outlined clearly enough in Fig. 170 impinges at a different angle, which has the effect of reducing the impact communicated to B to the approximate ratio Mv; and when we assume a

case, as in Fig. 171, still more closely approaching average practical conditions. the communicated impact becomes more nearly in the ratio $M\sqrt{v}$.

That this is so follows clearly from experience on tracks where the variations of speed are considerable, as notably on the four tracks of the New York Central & Hudson River Railroad, two of which are used for passenger service only, and two for freight only. The observed rate of wear per ton is nearly constant on these tracks, in spite of the fact that the proportion of engine-tonnage is several times greater on the passenger tracks.

As respects effect of increase of load, abrasion, other things being equal. should be in some approximately exact ratio to the *maximum* fibre-strain. If we assume an elastic cylinder or sphere to be rolling on a plane, a distortion of form will result from compression, rudely outlined in Fig. 172. The volume of this solid, shown in plan in Fig. 173, will be in direct ratio to the total load, but the maximum fibre-strain will be in proportion to the maximum ordinate CC', which varies more nearly as $\sqrt{L}$ or even $\sqrt[3]{L}$, according to the assumptions as to the surfaces in contact.

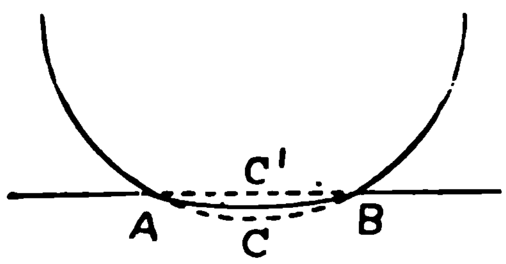

FIG. 172.

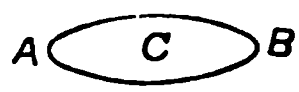

FIG. 173.

The subject is too obscure, and too unimportant for our immediate purpose, to consider further.

705. The observations of the Pennsylvania Railroad on the wear of rails on grades (par. 457) also tend to show that not more than half, or at most two thirds, of the total cost of rail wear can be considered to vary directly with the engine-tonnage, the car-tonnage remaining constant; whereas in the first edition of this treatise, based in the main on iron-rail statistics, the WHOLE cost of rails was assumed (and the writer believes with substantial correctness) to vary as the SQUARE of the weight on drivers, or at the rate, for small increments, of 200 per cent.* This change is one small evidence of the immense advantages which have resulted from the introduction of steel rails.

706. Of the remaining items of the cost of track, LINING AND SURFACING, in spite of apparent reasons to the contrary (discussed in par. 125), is affected by increased weight of engines in a considerably greater ratio than the rail wear, and tie renewals to a very considerable extent, although not quite so largely. We may not improperly take half the total cost of rails, ballast, ties, adjusting track, and switches, frogs, and sidings, as varying directly with the average weight on drivers, car-tonnage being

* For the reason (to those familiar with the elements of the calculus) that $d(x^2) = 2x dx$. See p. 90, old edition.

constant. With inferior steel rails it may be much more, but with such rails as may be had at the same cost by adequate care in inspection this estimate is a sufficient one.

707. The remaining items of maintenance of way, for BRIDGES AND BUILDINGS, are very slightly affected, certainly by not more, in ordinary cases, than ¼ ct. per train-mile, the whole being an allowance for interest and maintenance charges on heavier bridges.

708. REPAIRS OF ENGINES are affected much less than would be supposed by the weight of engines. Renewals constitute, as per Table 55 and others, from 40 to 50 per cent (under normal conditions, which can hardly be said as yet to exist on account of the rapid growth of traffic) of what appears charged to "repairs." Table 174 affords the means for estimating that considerably less than 50 per cent of the *first cost* of engines varies directly with weight, the remainder being, within moderate limits of variation, a constant.

Of the remaining cost, repairs proper, it is indicated in Table 54 *et seq.* and a number of others, that between 50 and 60 per cent is for labor only: an item which will be somewhat, but very slightly, affected by the weight of engines. The remaining expenditures, for raw materials and for wheels, axles, and tires, will vary nearly, but not quite, directly as the weight.

It would appear from these facts that 50 per cent of the cost of repairs may, with sufficient exactness, be assumed to vary directly with weight of engines, the remainder being constant, as has been already stated in par. 134.

709. THE COST OF FUEL for heavier engines hauling the same train behind them will not be largely increased. In not a few cases there would be an actual decrease. It is to be remembered that, even if heavier engines are used to overcome a somewhat higher grade, it is only for a short distance that the extra power is required. On all up grades below the maximum, and in descending all grades, the power required and exerted will be no greater than with the smaller engine, except the slight addition due to the weight of the engine itself, and this power will be somewhat more economically exerted (par. 579), owing to the heavier engine being less pushed. The constant wastage from radiation, stopping and starting, etc., estimated in par. 344 *et seq.*, at 50 per cent of the fuel consumption, will remain for the most part constant.

For all these reasons together, on something like two thirds of the length of ordinary railways the fuel burned per mile would be but slightly if at all affected by moderate (not over 20 per cent) differences in weight

TABLE 174.

COMPARATIVE COST PER TON OF VARIOUS SIZES OF ENGINES, BROAD AND NARROW GAUGE.

[Compiled from information furnished by the Baldwin Locomotive Works.]

American Type—Standard Gauge.

Cylinders.	Weight (net tons). Total.	On Drivers	Cost, 1886. Engine.	Tender.	Per Ton on Drivers.
12 × 22	24.	15.	$5,750	$950	$383
13 × 24	27.	18.	6,000	1,000	333
14 × 24	29.5	19.5	6,250	1,050	321
15 × 24	32.5	22.	6,500	1,100	295
16 × 24	36.	24.5	6,750	1,150	276
17 × 24	38.	25.5	7,000	1,200	275
18 × 24	41.	27.5	7,250	1,250	264
Mogul Type—Standard Gauge.					
16 × 24	37.	32.5	$7,250	$1,150	$223
17 × 24	39.	34.5	7,500	1,200	217
18 × 24	42.	37.	7,750	1,300	209
19 × 24	45.	40.	8,000	1,350	200
Consolidation Type—Standard Gauge.					
20 × 24	53.	46.	$9,250	$1,400	$201
21 × 24	59.	52.	9,750	1,400	188
NARROW-GAUGE ENGINES. *American Type.*					
10 × 16	16.5	11.	$4,750	$750	$432
11 × 16	18.	12.	5,000	775	417
12 × 16	19.5	13.	5,250	800	404
13 × 16	22.5	15.5	5,500	850	355
14 × 16	24.	16.5	5,750	900	357
Mogul Type.					
11 × 16	17.5	14.5	$5,250	$800	$362
12 × 16	20.	16.5	5,500	850	334
13 × 16	23.	19.5	5,750	900	295
14 × 16	25.	21.5	6,000	950	278
15 × 16	28.	24.5	6,250	1,000	255

TABLE 174.—*Continued.*

Consolidation Type.

CYLINDERS.	WEIGHT (net tons).		COST, 1886.		
	Total.	On Drivers.	Engine.	Tender.	Per Ton on Drivers.
15 × 18	28.	24.	$6,750	$950	$282
16 × 18	34.	29.	7,250	1,000	250

Comparison of the above table shows that the cost of engines increases at about the rate of $250 per inch of cylinder diameter, about $750 per extra driving-axle, and $250 per extra truck-axle; *which are builders' approximate rules*, starting from the 17 × 24 American engine as the standard or unit type.

Comparing the lightest and heaviest engines of each type, we find that the cost per ton on drivers of extra weight is but little over $100 per ton, viz.:

	Standard Gauge.	Narrow Gauge.
American, ...	$120	$182
Mogul, ...	100	100
Consolidation, ...	125	100

These figures indicate that, on an average, the first cost of additional power in engines is considerably less than half the average cost.

Messrs. Burnham, Parry, Williams & Co., proprietors of the works, state in an accompanying letter:

"Respecting the relative cost of narrow- and standard-gauge locomotives of the same weight and pattern, we have long believed that in many cases where narrow-gauge railroads have been contemplated it would be more economical and desirable to lay light rails 56½ inches apart, and use rolling-stock of the weight usual on narrow-gauge roads. We have, therefore, given much attention to the subject of your question. Our experience indicates that for engines of similar weight, dimensions, and pattern, differing only in gauge, there is no appreciable difference in cost. What extra expense is involved by the greater cross-measurements, is quite compensated for by the reduced length, as the greater distance between the frames permits of widening and shortening the fire-box, with corresponding reduction in length of frames and wheel-base. The shorter wheel-base enables the engine to curve more readily, removing in a measure one of the objections urged against the standard gauge. For these reasons we have been led to design a series of standard-gauge locomotives, precisely similar in all except gauge and the details of construction dependent thereon, to equivalent narrow-gauge engines, and which are offered at the same price."

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of engines, and on the remaining distance not more than 50 per cent of the fuel burned would vary directly with the weight and power exerted. As an average of entire runs, it is entirely adequate to assume that 25 per

cent of the total fuel consumption varies directly with the weight of engines hauling the same train over for the most part the same grades, and that the remaining 75 per cent is unaffected. On this basis, an engine 20 per cent heavier would average for entire runs not over 5 per cent more fuel to haul the same trains. The cost of supplying oil and water would vary in about the same proportion.

710. These various items are summed up in the following Table 175. As already stated, however, it is only under very exceptional circumstances and on a limited scale that it is proper to assume that differences of grade can or will be overcome in practice by the cheap and apparently simple expedient of increasing the weight of engines for freight service, and on roads enjoying a moderately large passenger traffic the same is very nearly true of passenger trains. The engines will in any case be made as powerful as is deemed feasible or expedient, for convenience in stopping and starting, and for occasional exigencies, if for nothing else; and anything which reduces their hauling capacity at the requisite speed between stations will be apt to result directly or indirectly in running shorter trains and more of them. This is far from an unmixed disadvantage under many circumstances (par. 89), but nevertheless it is a real disadvantage.

711. Table 175 itself makes clear why it is entirely improper to assume the use of heavier engines to meet the demands of heavier grades, by indicating that there is always a great economy in using the heaviest engines which the traffic will warrant. To double the weight of engine *to haul the same train* will only add some 14 per cent to expenses, according to Table 175. If by doubling the weight of engine we can also halve the number of trains, we immediately effect an immense economy in train-wages, engine repairs, fuel, and maintenance of way, exceeding more than threefold (Table 176) the increased expense per train-mile due to the heavier weight of engine. It is only when the grades are so very low (approximating closely to a level) that even a light engine can haul the fifty or sixty loaded cars, which are as many as can be conveniently handled with the present bad style of coupling, that heavier engines can be legitimately assumed to meet the requirements of a heavier grade; if even then.

TABLE 175.

ESTIMATED AVERAGE COST PER TRAIN-MILE OF DOUBLING THE WEIGHT OF ENGINES **to Haul the Same Train.**

[The percentage by which any given change of grade will require the weight of engines (or number of trains) to be increased is given in Table 171.]

ITEM. (As per Table 80, page 179.)	Average Cost of Item. Cents or Per Cent.	Per Cent Added by Doubling Weight of Engine.	Added Cost. Cents or Per Cent.
Fuel	7.6	25 per cent.	1.9
Oil, waste, and water	1.2	"	0.3
Engine repairs	5.6	50 per cent.	2.8
Switching-engines	5.2	Unaffected.	....
Train wages and supplies	15.4	"	....
Car maintenance and mileage	12.0	"	....
Renewals, rails	2.0	50 per cent.	1.0
Adjusting track	6.0	"	3.0
Renewals, ties	3.0	"	1.5
Earthwork, ballast, etc	4.0	"	2.0
Switches and sidings	2.5	"	1.3
Bridges and buildings	5.5		0.3
Station, terminal, and general	30.0		....
Total	100.0	14.1 per cent.	14.1

Perhaps one further exception should be made—when the traffic is so very light that it is not practically convenient to run very heavy trains, as when it is less than three to five freight trains per day.

712. Table 175 also explains why there is so great a tendency to increase the weight of passenger trains by supplying more luxurious accommodations. It is because—

1. A very powerful engine costs but little more to run than a light one (Table 175).

2. Coal consumption is but little increased by material differences in the weight of cars (par. 129).

3. Grades have but little influence upon passenger trains until they become very long (par. 397 *et seq.*), and by slight reductions of velocity *on up grades only* the effect of increased weight can be equalized if necessary (Table 120), running somewhat faster down hill. (See also Table 180, p. 579).

4. It encourages traffic to run more passenger trains (par. 89), and discourages it materially to attempt to crowd the traffic upon a few trains.

5. And more important than all, the increased luxury is a great attraction to travel, and added travel thus secured is of immense value to the property (pars. 37–41).

713. THE COST OF INCREASING THE NUMBER OF ENGINES TO HAUL THE SAME TRAFFIC, on account of a heavier grade, may be estimated as follows:

The number of trains is supposed to be increased by a change of maximum grade only, which will not ordinarily extend over one third of the distance. While running over the remaining distance, the work done on the train behind the engine will vary according to the weight or number of cars. While running on the maximum grade the power exerted by the engine will be the same, since in each case the engine is supposed to be fully loaded on that grade.

714. FUEL.—For reasons already enumerated (par. 344), about one half of the consumption of fuel will vary directly with the tonnage of the train; the other half, consisting of the fuel burned in stopping and starting (in part), getting up steam, loss by radiation, loss by head resistance, etc., making up in the aggregate the 50 per cent which is unaffected by the length of the train.

If, therefore, the maximum grade be increased on about one third the length of the road, while on the remainder the grades remain about the same, about half the consumption on two thirds of the distance, equal to all the consumption on one third of the distance, or 33 per cent of the entire consumption will vary directly with the net weight of the train; so that, if the grade were so increased as to take two locomotives instead of one to handle the same traffic, the fuel consumption would be as 1.0 to 1.67 at most, and not as 1.0 to 2.0, as might be over-hastily assumed. The aggregate cost of oil, waste, and water will vary in about the same proportion.

715. TRAIN-WAGES will of course vary directly with the number of trains, unless the change of grade in contemplation were so great as to shorten up trains so as to dispense with one brakeman, which can rarely happen.

716. STATION, TERMINAL, AND GENERAL EXPENSES will remain unaffected by any moderate change, but there is nothing by which they are so quickly affected as by a decided increase in the number of trains, and

a full 20 per cent of their aggregate may be considered as varying directly therewith.

717. Of the COST OF MAINTENANCE OF WAY we cannot directly account for an increase of more than one half to two thirds as a result of doubling the engine-mileage, the car-mileage remaining constant; but the facts given in par. 125 and its accompanying Tables 41-44 indicate that there is an indirect effect from multiplication of the number of trains which seems to cause all expenses for maintenance of way to increase *pari passu* therewith, including some items, such as those for policing, maintenance of ballast, road-bed, and ties, etc., etc., which should be affected but little, if any, apparently, by the precise number of trains over the road. It is to be remembered, in considering the tables referred to, that during the years which they cover the weight as well as the number of trains has increased enormously, which should naturally tend to keep maintenance of way per train-mile at a high figure; but after making all allowances for this difference, the chief cause for the singularly constant ratio of increase in maintenance of way and maintenance of rolling-stock is probably this: A continually advancing standard of maintenance is indispensable as the volume of traffic increases, and the cost of each step toward perfection increases about as the square of the number of steps. A very slight expenditure suffices to make track good enough for the passage of one train a day. A slight addition suffices for two or three trains a day, and makes a great improvement in the condition of the track. A much greater expenditure is necessary to fit the track for ten trains a day, and yet the visible advance in condition is much less; and, finally, as we get up to thirty or forty or fifty trains a day, a very great additional expenditure is found necessary—or at least expedient—although the visible advance of condition is very small. At any rate, the fact seems to be that even in so extreme an advance as from six trains a day to sixty (see top of page 128), the cost of maintenance of way *per train-mile* does not decrease, but rather the total cost per mile of road increases tenfold with the number of trains.

718. Investigation clearly indicates this to be THE FACT. We are therefore not justified in going behind it, to see whether we can explain it, but must take it as it is. If we do so, we are compelled to estimate that if by a change of grade we should double the engine-mileage needed for handling the same tonnage, we should also double the entire cost of maintenance of way. Making a concession of somewhat doubtful propriety to the fact that the car-mileage would remain the same, we may exclude the cost of bridges and buildings as unaffected; but this is the most

which can be done. Statistics do not seem to indicate that the total cost per train-mile on roads which handle light trains is sensibly less than on roads which handle heavy trains.

719. ENGINE REPAIRS should apparently vary directly with the miles run; but the indications are (Table 42 *et al.*) that as a matter of fact it is much less likely to do so than maintenance of way, owing in part to the large proportion of incidental expenses (see Table 57), which are not by any means doubled to maintain a double number of engines. There will also be a certain diminution of wear and tear from stopping and starting, etc. (see Table 85, page 203), from the fact that the trains to be handled are shorter. Taking both of these causes together, it is not probable that doubling the number of engines to move the same number of cars would increase engine repairs in the ratio of more than 1.00 to 1.75, and probably somewhat less.

720. CAR REPAIRS are certainly affected beneficially by having a less number of cars to a train. By referring to Table 86 (page 203) it will be seen that more than one third of the total cost of car repairs can be directly traced to the concussions of stopping and starting and making up trains. Much of this expense may disappear with the introduction of better couplers; but even this is doubtful, as an automatic coupler will permit of much more violence in running cars together, since a brakeman's life between the cars will no longer have to be considered. A diminution of at least 10 per cent may fairly be estimated as a result of running only half as long trains.

721. To these expenses, properly so called, is to be added AN INTEREST CHARGE ON THE COST OF THE ADDITIONAL MOTIVE-POWER REQUIRED by the higher grade, unless the first cost of these engines be included in the estimated cost of constructing the higher grade-line, before determining the difference in the capital investment.

This should be done because the addition of the required number of engines is really so much added to the original investment. Before the line is ready to handle the required traffic it is as necessary to have them as it is to have the track laid on the high grade-line and not on the other. In considering differences of distance (if not too great), or curvature, or rise and fall, this is not so. The total amount of equipment will be the same whatever the differences in that respect. We therefore estimate the expenses regardless of interest on the plant, and only consider differences in the cost of construction. Of the car equipment the same is true in the case of gradients. Whatever the grades, the number of cars will be the same; but as the number of engines is increased because

of the grades, and not for any difference of traffic, we must either include the difference in the cost of equipment as a part of the cost of construction, or add an interest charge to expenses. On the whole, it is more convenient to add the interest charge.

722. Putting together all these items which have been just considered, we obtain the summary given in Table 176, as the effect on operating expenses of so increasing the rate of grade as to double the number of engines required to handle a given

TABLE **176.**

ESTIMATED AVERAGE COST PER TRAIN-MILE, OF **Doubling the Number of Trains** TO HANDLE A GIVEN TRAFFIC; OR PROPORTION OF EXPENSES WHICH VARIES DIRECTLY WITH THE NUMBER OF TRAINS, THE CAR-TONNAGE REMAINING CONSTANT.

[The percentage by which any given change of grade will require the number of trains (or weight of engines) to be increased, is given in Tables 171 and 178.]

ITEM. (As per Table 80, page 179.)	Average Cost of Item. Cents or Per Cent.	Per Cent Added by Doubling Number of Trains.	Added Cost. Cents or Per Cent.
Fuel	7.6	67 per cent.	5.1
Oil, waste, and water	1.2	"	0.8
Engine repairs	5.6	75 per cent.	4.2
Switching engines	5.2	Unaffected.	....
Train wages and supplies	15.4	100 per cent.	15.4
Car maintenance and mileage	12.0	10 p. c. *less.*	(— 1.2)
Renewals, rails	2.0	100 per cent.	2.0
Adjusting track	6.0	"	6.0
Renewals, ties	3.0	"	3.0
Earthwork, ballast, etc	4.0	"	4.0
Switches and sidings	2.5	"	2.5
Bridges and buildings	5.5	Unaffected.	....
Station, terminal, and general	30.0	20 per cent.	6.0
Total of operating items	100.0	47.8 per cent.	47.8
To this is to be added the interest on the cost of one extra locomotive for one train-mile. Estimating the cost of the locomotive at about 10 000 times the cost of a train-mile, and the interest thereon at 6 per cent as about 600 times the cost of a train-mile; and estimating the average passenger-engine mileage to be 40,000 miles per year, we have, as the interest charge, per mile,			1.7
Making the grand total			**49.5**

traffic. When and if it can fairly be assumed that the weight of engines can be increased instead (par. 711), Table 175 gives the percentage of increase in expenses.

723. In the former edition of this work, this summary was materially different, especially as respects the effect of increasing the weight of engines, as shown in the following Table 177. The cause of the discordance is simply the change in conditions, in the writer's view, and not that either is essentially incorrect.

TABLE 177.

ESTIMATED COST OF DOUBLING THE ENGINE-TONNAGE FOR THE SAME CAR-TONNAGE USED IN THE FORMER EDITION OF THIS TREATISE.

[For statistics based for the most part on iron-rail track.]

ITEMS.	Total Cost. Cts. or Per Cent.	For a Double Number of Engines.		For a Double Weight of Engines.	
		Per cent increasing with Number of Engines.	Added Cost.	Per cent increasing with Weight of Engines.	Added Cost.
Fuel	10.0	90 per cent.	9.0	50 per cent.	5.0
Oil, waste, etc	2.0	90 " "	21.0	50 " "	1.0
Engine repairs	9.0	90 " "		33 " "	3.0
Train-wages	12.0	90 " "		Unaffected.	...
Track repairs	13.0	100 " "	13.0	200 per cent.	26.0
Road-bed repairs	7.0	100 " "	7.0	100 " "	7.0
Yards and structure	7.0	Included above.	....	Included above.	...
General and station	30.0	Unaffected.	....	Unaffected.	....
Totals	100.0	50 per cent.	50.0	42 per cent.	42.0

Assumed average, 48 cents per train-mile, or 48 per cent of operating expenses.

724. Assuming that under all ordinary circumstances, for moderate changes of grade, any increase must be met by an increase in the number and not in the weight of engines, we have 49.5 cents per train-mile, or 49.5 per cent of operating expenses, as the portion of the total expenses which will vary with increase of engine-mileage to handle the same business, which is not far from the cost of running an engine light, as it should be.

Multiplying this amount by 365×2, we have

$$\$0.495 \times 365 \times 2 = \$361.35$$

as the yearly sum *per daily train per mile of road* which varies directly with an increase of engine-tonnage for the same traffic.

If, now, we multiply this sum by THE PERCENTAGE OF THE INCREASE IN ENGINE-MILEAGE RESULTING FROM AN INCREASE OF 0.1 PER CENT in any ruling grade, we shall obtain the cost per daily train per mile of road of such increase. In other words, we obtain the cost per train of INCREASING the number of trains to handle the same fixed tonnage, or the saving per train by decreasing that number; i.e., we obtain the cost of using 1.1, 1.2, 1.5, or 2.0 trains, instead of one, to handle a given tonnage, or the saving by using 0.9, 0.8, or 0.6. That cost or saving is given in Table 178, and when multiplied by the estimated number of the trains on the grade for which the traffic was estimated, it gives the total cost or saving.

725. The cost thus obtained is not an absolute value, independent of the length of the road, as in the case of the similar values deduced for distance (Tables 88, 89), curvature (Table 115), or rise and fall (Table 124), but varies with the length of the road or division, inasmuch as the ruling grade increases the cost of operating the entire road, whatever the length of the ruling grade itself may be. Hence, to obtain the true value of reducing grade, it must be multiplied by the length of the road. It may appear that it should be multiplied by, not the actual but, the equated length, according to pars. 195–9, since we have there seen that 10 per cent more distance does not by any means add 10 per cent to operating expenses. But while this view is in a sense correct, yet the items which vary with a change of grade vary so nearly with distance likewise, that it would lead us too far to attempt any more accurate process of equating.

726. The cost per year in Table 178, divided by the rate of interest on capital, 0.06, 0.07, etc., will give the CAPITALIZED VALUE per daily train of avoiding an addition of 0.1 per cent to the ruling grade. Thus, to avoid an increase of 0.1 per cent in a 1.0 ruling grade, at 6 per cent on capital, and for a division 100 miles long, we have

$$\frac{\$2927}{0.06} = \$48,783 \text{ per daily train,}$$

TABLE 178.

ESTIMATED VALUE PER DAILY TRAIN OF AVOIDING AN ADDITION OF 0.1 Per Cent (5.28 FEET PER MILE) TO THE RATE OF ANY RULING GRADE.

[Cost per train-mile assumed at $1.00.]

Rate of Grade to be Changed.	Per Cent of Increase in Eng. Mileage for Each 0.1 Per Cent Added to the Grade (from Table 171).	Cost Per Year Per 0.1 Per Cent Increase in Grade.		Relative No. of Trains to Haul Same Traffic.	Relative Net Load.
		Per Daily Train = Preceding Per Cent × $361.35 × 100 Miles.	Per 1000 Ton-Miles Daily of Cars and Load as per Table 170.		
Level	25.9	$9,359	$17.50	1.00	100.00
0.1	20.9	7,552	17.77	1.26	79.44
0.2	17.5	6,353	18.03	1.52	65.72
0.3	15.1	5,456	18.23	1.79	55.93
0.4	13.3	4,806	18.48	2.06	48.60
0.5	11.9	4,300	18.75	2.33	42.88
0.6	10.8	3,903	19.03	2.61	38.32
0.7	9.8	3,541	19.34	2.89	34.58
0.8	9.2	3,324	19.74	3.18	31.48
0.9	8.5	3,072	20.12	3.47	28.82
1.0	8.1	2,927	20.38	3.76	26.58
1.2	7.0	2,530	20.87	4.37	22.88
1.4	6.3	2,277	21.43	4.99	20.04
1.6	5.8	2,096	22.26	5.63	17.76
1.8	5.5	1,987	23.18	6.29	15.89
2.0	5.1	1,843	24.26	6.98	14.32
2.2	4.8	1,734	25.22	7.69	13.01
2.4	4.6	1,662	26.23	8.41	11.89
2.6	4.4	1,590	27.22	9.16	10.92
2.8	4.2	1,518	28.21	9.94	10.06
3.0	4.0	1,445	29.02	10.74	9.31
3.5	3.6	1,301	31.42	12.92	7.74
4.0	3.4	1,229	35.10	15.29	6.55
5.0	3.2	1,156	44.82	20.74	4.82

COMPARISON OF THE THIRD AND FOURTH COLUMNS will show that while the cost *per daily train* of a given increase of grade is much less on the higher grades, because the number of trains is so much greater, yet that the cost per unit of traffic is greater as the grades are higher, as it naturally should be.

THE THIRD COLUMN IN THIS TABLE IS COMPUTED FOR A DIVISION 100 MILES LONG. For a greater or less length, increase in direct ratio with the length. Letting C = the sum thus obtained, we have

$$\frac{C \times \text{number daily trains (each way)} \times \text{tenths per cent of change of grade}}{\text{rate of interest on capital (0.06, 0.07, etc.)}} =$$

capitalized value of any increase or decrease in the rate of the given ruling grade, approximately. For greater exactitude, determine the correct percentage for the given change of grade from Table 171; or, for still greater exactitude compute the percentage from the train-loads given in Table 170 for the two given grades and the given type of engine.

THE FOURTH COLUMN is independent of the length of the division, and may be deduced from the third column by dividing it by the total weight of train as given in Table 170, × 200 + 1000.

or, for the moderate traffic of 10 daily trains per day (each way, in all cases). $487,833.

If the division be 110, 120, or 150 miles long, this sum, multiplied by 1.10, 1.20, or 1.50, will give the capitalized value, as nearly as may be. If the change in grade be 0.2 or 0.3 per cent, the capitalized value will be again increased in proportion. Thus, if the division be 150 miles long, and the comparison be between a 1.0 and 1.5 grade, we have

$$\$487,833 \times 1.5 \times 5 = \$3,658,750$$

as the approximate justifiable expenditure for avoiding the increase, for 10 trains per day and at $1.00 per train-mile. For greater exactness see note to Table 178, above.

727. Several recent French and German estimates of the value of reducing grades might be given, which do not differ radically from the preceding except in the constants assumed; in which latter respect they do differ radically. Table 179 gives one of the most recent and most nearly correct of such estimates. There are no estimates in English known to the writer, of an at all reliable character.

728. The greatly inferior loads hauled on foreign railways compared with American practice is conspicuously brought out in this table. An American engine with 40 tons on the drivers will haul in daily practice (Table 170),

	Tons.		Tonnes.
On a 0.5 grade, ...	1041	Against French	487
On a 1.0 grade, ...	644	practice,	274
On a 2.0 grade, ...	347	by Table 179.	131

The French loads are explicitly stated to be based on velocities of 25 kilos per hour, and indicate to an American eye very bad administration.

TABLE 179.

ESTIMATE OF THE VALUE OF REDUCING GRADES ON FRENCH RAILWAYS

[illegible] M. [illegible], Ing. en Chef Corps des Ponts et Chaussées. Abstracted from the [illegible] referred to in par. [illegible].)

Grade.	Gross Load [illegible] Tonnes.	Price per Train Kilo Francs.	Price per 1000 tonnes gross per Kilo. Francs.	
[illegible]	[illegible]	[illegible]	[illegible]	Diffs.
[illegible]	[illegible]	[illegible]	3 30	.28
[illegible]	[illegible]	[illegible]	3 [illegible]	.30
[illegible]	[illegible]	[illegible]	3 60	.32
[illegible]	[illegible]	[illegible]	3 92	.33
[illegible]	[illegible]	[illegible]	4 23	.32
[illegible]	[illegible]	[illegible]	4.56	.33
[illegible]	[illegible]	[illegible]	[illegible]	.36
[illegible]	[illegible]	[illegible]	[illegible]	.37
[illegible]	[illegible]	[illegible]	[illegible]	.39
[illegible]	[illegible]	[illegible]	7 65	.46
[illegible]	[illegible]	[illegible]	[illegible]	.45

The [illegible] table [illegible] will give a column corre[illegible] of Table [illegible]. No close correspondence can be expected, [illegible] decrease so much more rapidly with grade.

[illegible] engine, 56 tonnes (39.67 tons on drivers; [illegible]). The values in the last column are of a more general character. They are independent of the weight of the engine—at least within the limits of [illegible] practice.

THE PROPORTION OF TRAFFIC AFFECTED BY THE RATE OF RULING GRADE.

729. According to the character of the road, this may vary under certain conceivable circumstances between the extreme limits of 0 and 100 per cent. for both passenger and freight traffic. Freight traffic is by far the most affected, but there are at least occasional instances in which the freight traffic is so light and so little liable to grow that no appreciable value whatever can be assigned to reduction of grades below a certain limit. For, as the whole objection to gradie[illegible] so called, lies in their effect to limit the length of

duction of their rate has value only for such trains as they do in fact so limit. One train at least, the "way freight," is very often not so limited on all railways, and many minor railways are not so fortunate as to run anything else but way freights over their lines.

730. Nevertheless, as a rule, both the way freight and all other freight trains vary in length directly with the *de-facto* gradients, and should be assumed to do so. This does not at all assume that all trains will be fully loaded, for that is not a practicable result, but simply that the percentage of power wasted to power utilized will be sensibly the same for all grades and lengths of trains, or nearly enough so for all practical purposes. If so, it necessarily results that the PERCENTAGE of increase in trains will be much the same, whether they are fully loaded or not.

731. As respects passenger business (see par. 88), although it is much less directly and immediately affected by a change of grade than freight traffic, because of the higher speed, and the large surplus of motive-power required therefor and for stopping and starting, yet in the long-run, whenever the passenger business becomes considerable in volume or largely competitive, either the number or the weight of passenger engines must be materially affected by the rate of grade. The effect in the case of passenger traffic is far more irregular, but not therefore the less certain. A train, for example, might haul an extra car or two over any given grades, or haul the same cars over a heavier grade, as well as not, when the addition of yet another car to the train of say ten cars might require it to be cut in two, and so immediately double the motive-power required by increasing the load hauled only ten per cent. It is certain, moreover, that, whatever the margin of power deemed necessary for emergencies, if we reduce our grades and train resistance by any fixed amount, the weight of engines may always be reduced, or the weight of train increased, in the same proportion, and yet leave the same margin for emergencies or anticipated growth of traffic as before, however much or little that may be.

Hence a reduction of ruling grade has a positive and present cash value, even if every passenger train on the road will habitually run light for an indefinite number of years.

732. But this value will be but small when the passenger traffic will be light during the first few years after construction (par. 84) or when the traffic is not exacting as respects speed; or both, for the reason that the effect of any ordinary increase of grade, not sufficient to imply pushers for passenger as well as freight trains, may frequently be eliminated by a moderate reduction of speed between stations. The limits within which this is certainly and readily possible may be determined as follows:

733. In Table 180 are given the grades of repose for various passenger trains at various speeds, determined from the computed resistances in pounds per ton in Table 166 by simply dividing them by twenty. The limits of ordinary passenger trains are from four to twelve cars, but the table extends from no cars at all to sixteen.

These so-called "grades of repose" (see definition in par. 381) are grades equivalent to the addition which the train resistance makes to the actual plus or minus grade resistance. Subtracting them one from another, as is done in Table 180 B, we have THE AMOUNT BY WHICH THE GRADE IS IN EFFECT REDUCED BY REDUCING SPEED by a certain number of miles per hour. If, then, it be admissible to consider the speed of a 4-car train to be reduced from thirty miles per hour to fifteen or twenty miles, we can (Table 180—B) use a grade—

$$0.49 - 0.16 + 0.15 = 0.48 \text{ per cent,}$$

or $0.49 - 0.16 = 0.33$ per cent higher than if a speed of thirty miles per hour were essential on the grade as well as elsewhere. We shall shortly see (Table 183) that the loss of time in so doing is less than is often supposed. When to this is added the relief gained by momentum if the foot of the grade can be approached at thirty or forty or fifty miles per hour (Table 118 and par. 465) we have considerable lee-way in respect to pas-

TABLE 180.

GRADES OF REPOSE FOR PASSENGER TRAINS OF VARIOUS LENGTHS AT VARIOUS SPEEDS.

[17 × 24 American engine—cars averaging 25 tons each. According to the formulæ given in Table 166.]

[For grades of repose of freight trains, see Table 120.]

KIND OF TRAIN.	Weight Tons.	GRADES OF REPOSE, PER CENT, FOR VELOCITIES IN MILES PER HOUR.							
		15	20	25	30	40	50	60	70
Engine only.....	56	0.60	0.88	1.24	1.69	2.81	4.26	6.03	8.12
" and 2 cars..	112	0.45	0.62	0.83	1.08	1.74	2.58	3.62	4.83
" " 4 cars..	168	0.40	0.52	0.69	0.88	1.38	2.02	2.81	3.74
" " 8 cars..	280	0.36	0.46	0.58	0.73	1.10	1.58	2.12	2.87
" " 12 cars..	392	0.34	0.42	0.53	0.65	0.98	1.39	1.89	2.49
" " 16 cars..	504	0.33	0.41	0.50	0.62	0.91	1.28	1.74	2.28

TABLE 180 B.

INCREASE OF GRADE WHICH WILL BE COMPENSATED FOR BY A REDUCTION OF TRAIN SPEED FROM EACH OF THOSE GIVEN IN TABLE 180 TO THE NEXT LOWER.

[Deduced by subtracting each of the grades of repose from the next higher.]

KIND OF TRAIN.	REDUCTION OF EQUIVALENT GRADE BY REDUCING SPEED FROM—						
	20 to 15	25 to 20	30 to 25	40 to 30	50 to 40	60 to 50	70 to 60
Engine only	0.28	0.46	0.45	1.12	1.45	1.77	2.09
" and 2 cars...	0.17	0.21	0.25	0.66	0.84	1.04	1.21
" " 4 cars...	0.13	0.16	0.19	0.50	0.65	0.78	0.93
" " 8 cars...	0.10	0.12	0.15	0.37	0.48	0.54	0.75
" " 12 cars...	0.08	0.11	0.12	0.33	0.41	0.50	0.60
" " 16 cars...	0.08	0.09	0.12	0.29	0.37	0.46	0.54

While it is probable that these differences represent somewhat more than the actual differences in the resistance to be overcome (par. 655), it is quite certain that they are not nearly large enough to fully represent the combined effect of the lower resistance and greater cylinder and boiler power of the engine at lower speeds (par. 557).

low grades, we may now profitably refer back to Chap. X., the assumptions made in which we have just substantiated. While such estimates as are here made, as has been often stated, cannot be regarded as positive and exact, even when carefully revised to suit individual lines, the possible margin of error is too small to seriously modify, if corrected, the moral which they are calculated to convey, which is that WRONGLY DIRECTED expenditure is at the root of much of the financial difficulties of railways.

In the example referred to one detail of occasional importance has been neglected, viz.:

THE EFFECT OF A DIFFERENCE IN RULING GRADE ON THE COST OF DISTANCE, CURVATURE, AND RISE AND FALL.

738. While we have seen in Chap. X. that ordinarily, when two lines differing in ruling grade are to be compared, the importance of the difference in gradients and in traffic advantages combined will be so great that such differences as may exist in any or all the minor details may be neglected without affecting the decision, yet when the comparison between two lines differing in ruling grade is so close that it is desirable to determine accurately the effect of differences in the minor details also, the difference in the rate of the ruling grades of the two lines makes it necessary to treat the minor details somewhat differently from merely subtracting the amount of distance, curvature, or rise and fall on the two lines from each other, and computing the value of the difference only, as we have done heretofore.

739. Suppose the case of two lines, each 100 miles long, and with precisely the same amount of curvature and rise and fall, but with a ruling grade on one line of 0.8 per cent and on the other of 1.6 per cent. It appears at first sight as if in this case, whatever the amount of curvature or rise and fall, they might be balanced against each other and neglected; but consideration shows this to be so far untrue that, inasmuch as more trains will be run over one line than the other, the cost of each degree of curvature and each foot of distance or rise and fall will be greater on one line than the other, so that the line having the heavier gradients will be more objectionable in proportion to the amount of curvature or rise and fall *which there may be on both lines alike.* In other words, just as there is a certain cost of operating each train-mile of distance, so there is a

certain cost of operating what we may call each train-degree of curvature and each train-foot of rise and fall.

If, therefore, in such an instance as that supposed, the two lines had much curvature and rise and fall, the money value in favor of the lower grade would be considerably greater than if both lines alike were nearly straight and had very little rise and fall.

740. This difference of value should properly find expression in a different assumed cost per train-mile; and in estimating the value of a projected improvement to a line already in operation it would be so expressed, since the curvature and rise and fall would already have had its effect, much or little as the case might be, to increase the operating expenses by which we gauge the value of reducing grade.

But in the case of a new road we have not this advantage, inasmuch as we cannot foresee the exact cost of each item of operating expense. The most feasible method therefore for approximating to what we really desire, the DIFFERENCE in operating expenses per train-mile on the two lines, is this:

741. *First.* Estimate the cost per year of all the curvature and rise and fall on the low-grade line for the estimated number of daily trains, according to Tables 115 and 124.

Secondly. Make the same estimate for all the curvature and rise and fall on the high-grade line, for the estimated increased number of trains required to handle the same traffic, as determined by Tables 170, 171, and 178.

Thirdly. Subtract one from the other for the net difference.

Similarly for any difference of distance: If the high-grade line be the longer, the cost of operating the extra distance on the high-grade line must be estimated for the number of trains on it; while if the low-grade line be the longer, by the same amount the cost of operating the extra distance must be estimated for its smaller number of trains, and hence will be somewhat smaller than for a similar excess on the high-grade line.

742. There is this further caution: Inasmuch as the traffic, and hence number of cars per day or per year, is supposed to be the same by either line, the only difference being that shorter trains and more of them are run over the high grade, the same cost per train-mile cannot, strictly speaking, be assumed the same for both lines. We have estimated in Table 176 that the cost of doubling the number of trains for the same traffic is 49.5 cts. per extra train-mile, or 49.5 per cent of the average cost. For a change of grade so considerable as to halve the number of cars per

train, therefore, the relative cost per train-mile in the two lines would be as 1.00 to $\frac{1.0 + 0.48}{2}$, or 1. to 0.74, and proportionately for less considerable differences of grade. In other words, whatever wear and tear results from the number of cars moved over the line, as well as the expense of loading and billing the freight in them, etc., is unaffected by the change of grades. Whatever is due to the engine increases *pro rata* with the number of trains.

743. For still another reason than those just mentioned, it can rarely be essential to enter into minutely accurate calculations as to the minor details to decide on one line or the other. When the comparison between two lines becomes so close that it would otherwise be necessary, the possible effect of the two lines on volume of traffic ought alone to outweigh it, and the prudent rule becomes—

1. When the company is or soon may be poor (and it is no more than common prudence to assume that it will be embarrassed for means at some time in the near future, when it is not backed by a great system of profitable lines in operation), *take the line of lowest first cost.*

2. When immunity from financial embarrassment is assured, *take the line which offers the most promising conditions for future growth of traffic.*

3. Only when the two lines are substantially equal in both these respects enter into such minute calculations as these just suggested, and whichever line be selected no serious harm can then result.

744. Having determined the justifiable expenditure to obtain low grades, we have only taken the first step toward their proper adjustment. Some of the worst sacrifices of gradients are made without effecting any saving of cost whatever, simply from inattention to its importance, or from attaching exaggerated importance to losses of distance or curvature, or from insufficient study of the topography, leading to a too hasty conclusion that all has been done which can be done, when in fact a very little study would lead to far better results.*

* It is an invidious and unpleasant thing to say, but the importance of the

This question of how to get the lowest grade which the region admits of, at a given cost, is discussed in Part V. and Appendix C. The four following sub-departments of the general problem of gradients yet remain to be considered:

1. The use of assistant engines with high "bunched" grades.
2. The balance of grades for unequal traffic.
3. Limiting curvature, and the proper compensation therefor.
4. The limit of maximum curvature.

These questions we will consider in their order.

caution thereby conveyed seems to justify saying it: Out of a hundred men putting a line through either easy or difficult country, *but especially through easy country*, the writer's observation is that all but four or five of them will adopt rates of grade from ten to fifty or even a hundred per cent higher than the other five will obtain at the same cost; and the same holds true as to amount of curvature.

CHAPTER XVI.

ASSISTANT ENGINES.

745. THE general use of assistant engines, commonly called PUSHERS, is a comparatively modern innovation. So recently as 1873, Gen. Herman Haupt,* in a paper on gradients, felt compelled to say that he was making "an attempt to prove, contrary to the generally received opinion," that undulating gradients below the limits of the maximum do not necessarily increase expenses materially, and "that the use of higher gradients for part of a given distance will often result in greater economy of operation than a lower and uniform gradient for the whole distance."

This statement has now become a truism. Driven to economy by the necessities of competition, the use of assistant engines, even on lines ill adapted to their most advantageous use, has become very general in recent years and is constantly extending, although they are even yet not used on more than a proportion of the lines which might use them with advantage and economy, so that their use is one of the most hopeful directions in which further economy may be sought, especially on low-grade lines, where the trains hauled even by one engine are of fairly profitable length, but might be readily increased by help at a few points.

What has been accomplished, however, is that whereas assistant engines were formerly used only in exceptional instances on very heavy grades, their use has now multiplied many-fold, and the expediency of using them when possible, even at quite frequent intervals, is universally admitted by skilled railway officers. Some of our earliest and greatest engineers, as notably the engineers of the Baltimore & Ohio, Pennsylvania, and Erie railways, distinctly contemplated the use of pushers and adapted

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* See *Railroad Gazette*, July 5, 1873.

their lines thereto; no doubt in part because of the topographical conditions in passing the Alleghanies, but in part also because of the singular foresight and sagacity which the great engineers who laid out those lines showed in many ways. But these precedents have not been generally recognized as establishing a general principle until very recently, nor can it be said to be yet established as fully as it should be.

746. The presumption is strong in laying out every line, that advantage can be derived from laying out the grades for the use of assistant engines, because of the fact that topographical conditions always require more or less irregularity of gradients. The usual law is that the grades will be for long distances very low and easy, or can be made so at slight cost, but that for much shorter distances much higher gradients will be unavoidable. By adapting the line to the use of assistant engines on these higher grades we are enabled to utilize the full advantage of the lower grades, by making up our trains to correspond to them, so that long trains can be handled over the entire line by a single crew, without breaking it up into sections, and the full power of the motive-power actually in use at all points on the line be more nearly utilized.

747. The adoption of the opposite policy, attempting to get a line of a low uniform gradient through a country of any difficulty whatever, is very apt to be enormously expensive, and to be possible at all only by frequent undulations, considerable detours, and much higher gradients over most of the line than than there is any necessity for using. This results from the fact that it sets at defiance one of the broadest and most nearly universal laws of physical geography,—to which there are few and rare exceptions on the whole face of the globe,—that long stretches of easy plains or gently sloping valleys penetrate at intervals to and into the very heart of even the roughest regions, leaving short sections only over which high gradients are unavoidable. By following these easy routes as long as we can we accomplish over most of our line three desirable ends at once:

1. We get the cheapest line.
2. We get the lowest through grades; and,

3. More than all else, WE CONCENTRATE THE RESISTANCES into the remaining more difficult section, so that the motive-power on it can be accurately adapted to the work required and kept fully at work over the distance where it is used, thus making it almost

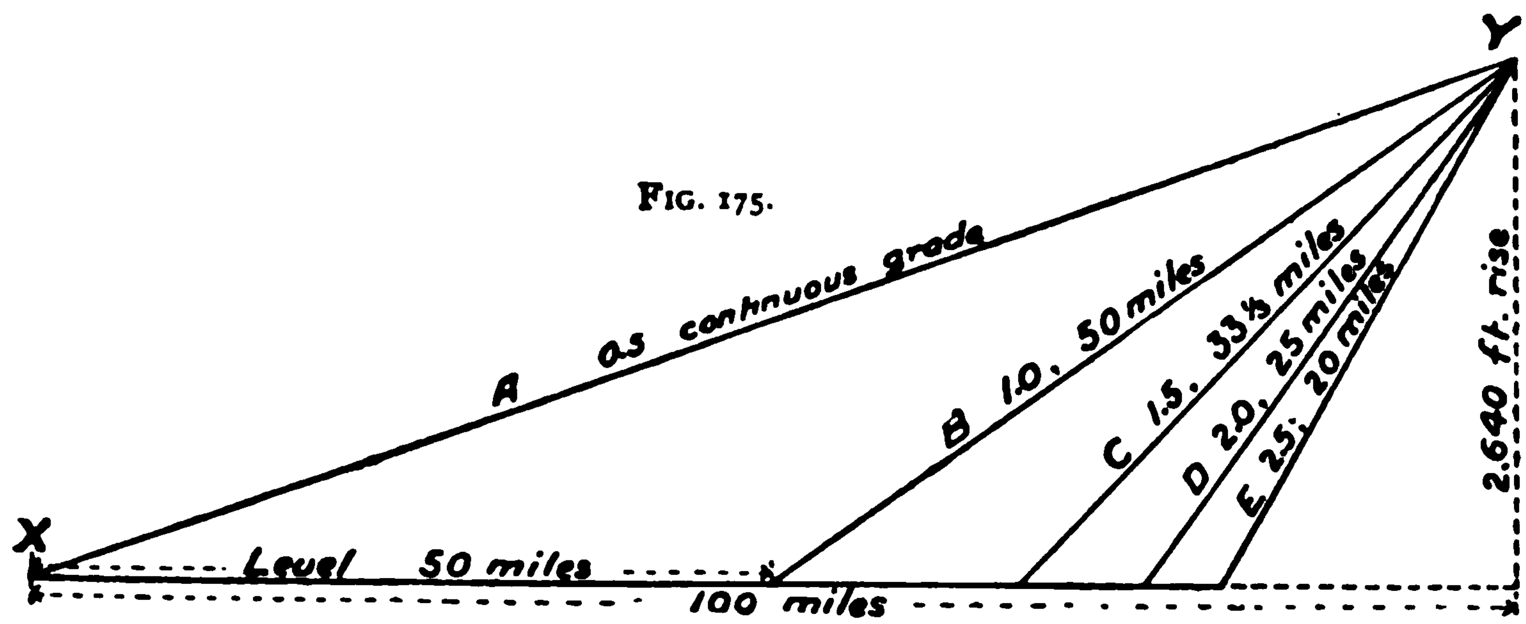

FIG. 175.

TABLE 181.

COMPARATIVE WORK ACCOMPLISHED BY AN ENGINE IN RUNNING 100 MILES FROM *X* TO *Y*, FIG. 175, AND MAKING A RISE OF 2640 FEET THEREON OVER THE VARIOUS GRADES SHOWN.

LINE, FIG. 175.	Distance Miles.	Grade p.c. Grade p.c.	Net Load. Tons.	Total Ton-Miles Hauled by one Trip of Through Engine.		Total Engine-Miles to Haul 2675 Tons 100 Miles.		Per Cent of Efficiency.
A......	100	0 5	1147		114,700		233	100.0
B......	50	Level.	2675	133.700	169,250	50	238	102.1
	50	1.0	711	35.550		188		
C......	66⅔	Level.	2675	178,400	195,200	67	244	104.7
	33⅓	1.5	504	16,800		177		
D......	75	Level.	2675	200,600	210,175	75	249	106.4
	25	2 0	383	9.575		174		
E......	80	Level.	2675	214.000	220,080	80	256	109.9
	20	2.5	304	6,080		176		

The fifth column indicates that a single through engine, which drops cars to correspond to its hauling capacity at the foot of the grades B, C, D, E, Fig. 175, will make vastly more ton-miles on the high grades than the low. This, however, is unfair. The true test is: *How much motive-power will it take to carry a whole train-load*, or a thousand train-loads, through, the typical train weighing by assumption above 2675 tons. The two last columns show that, from this more correct point of view, there is a certain disadvantage in the higher grades, but a most trifling one, *so long as the resistances are concentrated*, so that engines can be at all times fully loaded. But if scattered, so that it is necessary to run short trains FROM *X* TO *Y*, because of the occasional steep grades, the disadvantage becomes enormous.

a matter of indifference what rate of ascent we adopt on our more difficult sections—a fact which powerfully tends to still further reduce the cost of construction over those more difficult sections. Table 181 and Fig. 175 illustrate fully how and why this advantage arises, and should be carefully studied.

748. Even where we are unable for any reason to follow the valley lines which usually penetrate far into hilly or mountainous regions, as for instance when the valleys are impracticable, or are less practicable than the ridges, it is still true that pusher gradients will almost invariably fit the country better. The all but universal law of topography is that, when the ground is not a dead level, transitions from one level to another, whether on a large scale or on a small scale, are of the form shown in Figs. 176 and 177.

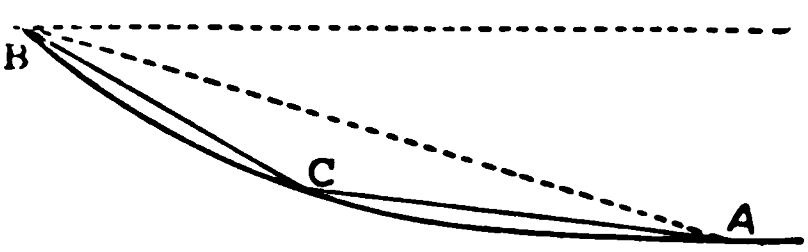

FIG. 176.

If on a small scale, we may simply adopt the dotted profile AB, and make the fill at C or cut at B. If on a larger scale, say for a total rise of 50 or 60 or 80 feet, it becomes impossible to do this, especially if the necessity occurs at many points, and we are reduced to adopting the profile ACB, making BC the ruling grade of the line, or else to one of the two expedients shown in plan in Fig. 177—either to run right over the obstruction with almost a tangent line, giving the dotted profile AB, in Fig. 178, or to sacrifice curvature and distance and obtain the full-line profile. The first has been done to a most unfortunate extent in the prairie-lines of the West; the last is almost always the proper course, if it saves an increase of ruling grade, even when necessary at many points on the line.

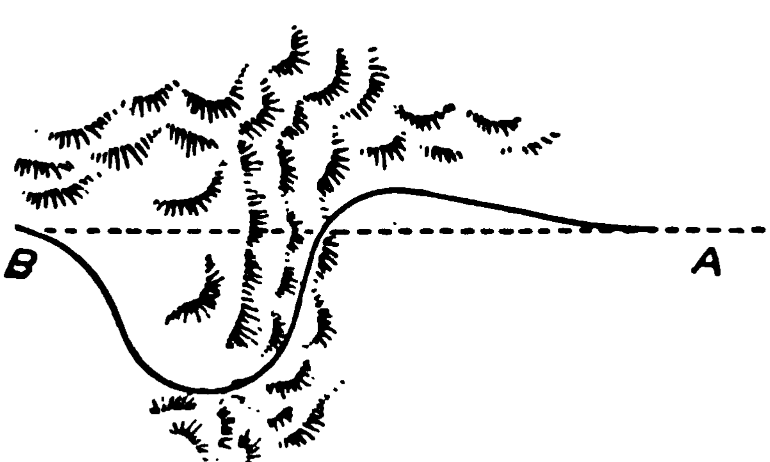

FIG. 177.

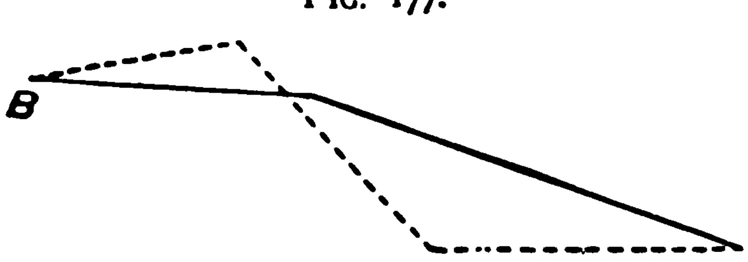

FIG. 178.

749. But when the rise to be overcome becomes more consid-

erable, as 100 or 200 feet, even this course is rarely convenient. To obtain an equivalent for the full line *AB*, Fig. 177, we are then compelled, usually, to adopt a costly line hanging upon the slopes of such supporting ground as can be had in order to obtain the dotted profile *AB*, Fig. 176, or the solid-line profile *AB*, Fig. 178. When we have got it—assuming that we can and do get it—we have even then, in all probability, been compelled to use a higher grade than it is at all necessary to use on the remaining and easier portions of the line. If so, we have not only spent a great deal of money where we have difficulties, but have injured our line where we have no difficulties.

750. The alternative is to treat the difficult ground as a separate feature; to maintain the lowest grades we can, on the ground where we have no difficulties; to push these low grades as far as possible to some point *C*, Fig. 176, as near as may be to the rise; and then to adopt some entirely different and much higher grade *BC*, conforming as closely as possible to the natural surface, with a view of using auxiliary power or "pushers" on it, thus not only saving our money on the parts of the line which are naturally most costly, but retaining all our natural advantages elsewhere which cost us nothing.

751. In other words, the secret of the vast economies which may often be realized by the skilful use of assistant engines is this—that as respects construction we work with Nature instead of against her, and that as respects operation we gain a like advantage by keeping every engine while running fully at work, the greater portion of the hard work in foot-pounds being done on a small portion of the division, with such favorable through grades, in many cases, that there is little more need for an engine on the remainder of it, than to keep the longest trains moving and under control. It is a truth of the first importance, that the objection to high gradients is not the work which engines have to do on them (see Table 181), but it is the work which they do NOT do when they are thundering over the track with a light train behind them, from end to end of a division, in order that the needed power may be at hand at a few

scattered points where alone it is needed. But if we may give this additional motive-power its work to do once for all, and have done with it, high summits cost very little, and an increase of the rate of grade costs, practically, nothing whatever. At the points of greatest difficulty we are independent of the rate of ascent and in a great degree of the elevation attained, and are therefore at liberty to concentrate our efforts and expenditure on the more tractable portions of the line, where a few feet per mile reduction in grade (see Table 170 and Fig. 169) may be of enormous value.

752. In this way it is in every way practicable to secure lines over tolerably high summits and through difficult country which shall approximate closely in operating value to the most favorable existing examples of low-grade lines. On the other hand, BY SEEKING FOR WHAT WE DO NOT REQUIRE, by defying the obstacles of nature and forcing them to conform throughout to the Procrustean standard of a uniform ruling gradient, we shall enormously increase the cost of construction, and in the end find that we have a far more costly line to operate than if we had "stooped to conquer" by boldly conforming to the topographical conditions and then skilfully forcing them to serve our purpose. This goes so far that it is true policy in very many instances in difficult country to make boldly for the "meeting of the waters" at the summit, even at the cost of a higher summit, rather than to zigzag up and down and from side to side in a costly effort to avoid a continuous succession of transverse valleys and other petty obstacles, each of which has us at great disadvantage.

753. The advantages of the use of pusher grades are not at all confined to high grades, but on the contrary are even greater proportionately for low grades, provided only that there be business enough to fill up the trains, and couplings good enough to permit of handling long trains. On roads of light and irregular traffic there may be no great advantage in them; but many roads having large traffic, which must be hauled cheaply because it pays little, are habitually using pushers on gradients as low as 0.5 to 0.6 per cent. For example, freight pushers are used on the

Hudson River Railroad, nearly 95 per cent of which is a dead level, and the remainder over summits a few feet high on 0.4 to 0.5 grades.

THE POWER OF ASSISTANT ENGINES.

754. By the use of assistant engines the available motive-power is approximately doubled or trebled; and it is evident that economy in motive-power requires that the rates of these grades should be proportioned to each other as nearly as possible, in order that neither grade may be disportionately low, but that the true RULING grade may be—not necessarily either the higher (pusher) grade or the lower grade, but that one which involves most difficulty and expense in reduction.

With certain provisos which we will shortly consider, the determination of a practically exact balance of gradients for the use of one or more assistant engines is a simple matter. If the assistant engine be of the same weight as the through engine, the load to be hauled by each engine is reduced one half. If there be two pushers, the load to be hauled by each engine is reduced to one third of what it was. If the pusher have, say, 10 or 20 per cent more tractive power than the through engine, the train is in effect cut into two unequal parts, that remaining to the through engine being $\frac{1.0}{1.0 + 1.10}$, or $\frac{1.0}{1.0 + 1.20}$, i.e., 47.6 or 45.5 per cent of the original weight of the train behind tender. The grade on which the through engine can haul that per cent of its load on a given through grade will therefore be the corresponding pusher grade for pusher engines of such weight.

755. By the aid of the long Table 170, the process of determining such pusher grades for any through grade is made one of mere inspection, as practical convenience requires. For example, to determine the pusher grades corresponding to through grades of 0.5 per cent, we have—

	Light American.	Average Consolidation.
Net load behind tender, on 0.5 grade	504 tons.	1147 tons.
Half of which is	252 "	573½ "
Corresponding pusher grades	1.24 per cent.	1.30 per cent.
$\frac{10}{21}$ of load, for pushers 10 p. c. heavier, is	241 tons.	550 tons.
Corresponding pusher grades	1.31 per cent.	1.36 per cent.
$\frac{10}{22}$ of load, for pushers 20 p. c. heavier, is	229 tons.	522 tons.
Corresponding pusher grades	1.38 per cent.	1.44 per cent.
$\frac{1}{3}$ of load, for 2 pushers of equal weight	168 tons.	382 tons.
Corresponding pusher grades	1.87 per cent.	2.00 per cent.

From these examples it will be seen that differences in type of engine make no considerable difference in the balance of grades, and we shall hereafter consider the average Consolidation type only.

756. If the pusher were a tank engine having no tender, it in effect adds the weight of the tender to the train hauled by the pusher; so that to make the preceding calculation we should first have to subtract the weight of tender thus saved from the total weight of train, and then divide the remainder only between the through and pusher engines, in the above proportion, which would increase the rate of the admissible pusher grades materially.

In this manner Table 182 was computed, which gives the proper balance of grades for an ordinary Consolidation, or practically for any other engine, except tank engines, which are separately noted.

757. The requirements of the passenger service naturally favor the adoption of higher through grades rather than pusher grades, since undulating gradients, however steep, have little effect to impede hauling any trains ordinarily desired, when the rise on a single grade is not great. Owing to the decrease of train resistance at slow speeds (Table 166) and the simultaneous increase in the tractive power of the cylinders, the limit at which a high and long grade can certainly be operated without a pusher is still further increased. The ultimate limit for the operation of a pusher grade by a single engine in passenger service, beyond which pushers must be used for passenger as well as freight trains, may be determined as follows:

The most that would be demanded of an ordinary 17 × 24 passenger engine, weighing with tender 56 tons, more or less, such as is assumed in the table of train resistance (Table 166), is that it should haul—as an average of a whole division and every day in the year, and not for exceptional performances,—

4 cars, or 168 tons, gross weight of train.	8 cars, or 280 tons, gross weight of train.	12 cars, or 392 tons, gross weight of train.
At 60 miles per hour maximum speed on a level.	At 50 miles per hour maximum speed on a level.	At 35 miles per hour maximum speed on a level.

758. Now the tractive power which such an engine is capable of exerting in every-day practice at freight speeds of 15 miles per hour would be nearly if not quite 10,000 lbs., there being from 40,000 to 44,000 lbs. on the drivers. Therefore the engine will be capable of exerting a MAXIMUM tractive force on these trains, at freight speeds of about 15 miles per hour of 10,000 lbs. ÷ the weight in tons, or

59.5 lbs. per ton,	35.7 lbs. per ton,	25.5 lbs. per ton.

TABLE 182.

BALANCE OF GRADES FOR THE USE OF ASSISTANT ENGINES.

[Correct within an unimportant percentage for all classes of engines and conditions of service, the through and pusher engines having the same weight and tractive power.]

THROUGH-GRADE WORKED BY ONE ENGINE.	Net Load (Tons) for Average Consolidation.	GRADE UP WHICH THE SAME TRAIN CAN BE HAULED BY THE AID OF—		
		One Pusher.	Two Pushers.	Three Pushers.
Level.	2675	.38	.74	1.08
.05	2370	.47	.87	1.25
.10	2125	.57	1.00	1.41
.15	1936	.66	1.13	1.57
.20	1758	.75	1.26	1.74
.25	1618	.84	1.39	1.89
.30	1496	.94	1.52	2.05
.35	1392	1.03	1.64	2.20
.40	1300	1.12	1.76	2.35
.45	1220—	1.21	1.88	2.49
.50	1147	1.30	2.01	2.64
.60	1025	1.47	2.24	2.92
.70	925	1.65	2.47	3.20
.80	842	1.82	2.69	3.45
.90	771	1.99	2.91	3.70
1.00	711	2.16	3.13	3.95
1.10	658	2.32	3.33	4.20
1.20	612	2.48	3.55	4.42
1.30	572	2.64	3.73	4.65
1.40	536	2.81	3.93	4.87
1.50	504	2.96	4.13	5.07
1.60	475	3.13	4.32	5.27
1.80	425	3.43	4.68	5.68
2.00	383	3.72	5.03	6.04
2.20	348	4.01	5.35	6.40
2.40	318	4.30	5.67	6.73
2.60	292	4.57	6.00	7.05
2.80	269	4.86	6.30	7.34
3.00	249	5.10	6.58	7.63

If we assume ⅕ instead of ¼ adhesion, we simply reduce the tractive power of an average Consolidation (Table 170) from 10 tons to 8 tons. The ratio of the GROSS weights of trains on various grades remains unchanged, and the ratio of the weight behind tender would remain so likewise if the gross weight of engine were reduced one fifth, or by 15 tons. As it is not, the column headed 8.0 tons tractive power in Table 170 should be 11 tons greater to give the net loads, and we find the pusher grades to be—

heavier through expresses consisting of 6 to 8 cars, each averaging over 25 tons, would find difficulty in ascending the mountain without an assistant engine even at very slow speed.

On the Middle Division, having very easy grades, not over 21 ft. per mile at any point, as many as 10 heavy cars, but not more, are hauled by a single passenger engine, making, however, even with this train, high average speeds. Similar trains are hauled over the New York Central road for the entire distance from New York to Buffalo, except that a pusher is used for the grade of about 1 per cent at Albany.

761. Except within the limits above noted passenger trains as well as freight must be assumed to require pushers. The more certain it is that high speed will be required at all points, the more likely they are to be required; and wherever it appears likely that the passenger traffic will be important and competitive it may, for a moderately prosperous road, be giving no more than due weight to the great and permanent value of easy gradients to assume that all trains, both passenger and freight, will ultimately require helping engines, especially as the tendency to increase the weight of passenger trains and cars is strong.

The assumption made as to passenger helpers will make a considerable difference in a comparison of gradients, for if they be assumed to be used, the advantage of easier gradients over moderately favorable through gradients will be much less than if they be not assumed, the [illegible] passenger [illegible] rates of grade can hardly be [illegible].

762. [illegible] grades the effect of fluctuations in the [illegible] the grades to each other must [illegible]. The effect of these differences [illegible] usually be that the [illegible] grades will be higher than [illegible] pusher grades will be greater [illegible] so that the latter will need to be reduced [illegible] in order to give a true [illegible] may be permissible [illegible] momentum can be [illegible] the normal rate [illegible] increase its limiting effect [illegible] less care has been used to ease the grades [illegible] be required. Even if this has been [illegible] occasional irregular stress and [illegible] will be allowed far more [illegible].

763. On the other hand, the lower through grade will very commonly be cut up into such short stretches that momentum will, or may be made to, reduce its apparent rate very materially, and even if not, moderate improvements in the future will often suffice to accomplish this. Moreover, it is always comparatively easy to foresee and guard against limiting effects from stops.

True economy will ordinarily dictate, therefore, that THE RESISTANCE ON THE PUSHER GRADE SHOULD BE AT LEAST TEN PER CENT LESS THAN AN APPARENT BALANCE REQUIRES if attainable at moderate cost, with the following proviso:

If the rate of the pusher grade be, from its cost or otherwise, the fixed element beyond control, as often happens, then the rate of the lower through grade should be reduced at any reasonable cost (it is usually more at the cost of care than money) to *and a little below* the full extent which an apparent balance requires: in accordance with the sound general principle, that the links in a chain whose strength we cannot control nor exactly foresee should be the weakest, and not those whose strength we can control and can foresee.

764. Again, the lower the rolling-friction the greater the proportionate effect of gradients upon the total train resistance, and consequently the lower must be the rate of the higher pusher grade. As we have assumed (par. 623 and Table 170) 8 lbs. per ton rolling-friction, which is probably from 2 to 4 lbs. high for the slower working speeds, the rate of the higher grade should be from 0.1 to 0.2 per cent less than theory would otherwise indicate, where possible, for this reason alone.

765. A variation in the weight and power of the assistant engines affords a means of equalizing minor inequalities in the balance of gradients, should such be discovered, but this should be counted on with caution in original location. To count on using pusher engines lighter than the through engines would ordinarily be very bad practice. It would be preferable to save money and length of pusher grade by using a steeper rate of grade. To count on using heavier pushers is open to three objections: (1) The tendency is always to use heavier and heavier through engines, and a point will then soon be reached where corresponding increase in the weight of pusher engines would be objectionable or impracticable; (2) It imposes a greater tax upon the rails and track at the very point where the alignment makes it most objectionable; (3) Such gain as is possible in this respect is very apt to be required and used to make up for the inequalities in what was supposed to be a correct balance of gradients, *the tendency always being to get the rate of the pusher grades*

too high for a correct balance with the lower grades. In actual practice, at the present day, it will be found that pusher engines usually are a little heavier than the through engines, and yet that the pusher grades are no higher in rate than Table 182 would indicate, the excess being used, apparently, for the preceding and following reasons, and not to provide a true balance under normal conditions.

766. If the rate of adhesion be low, the admissible rates for the higher gradients is very materially decreased, as shown in Table 183, for the reason that the percentage of effect lost in moving the engine itself is very materially greater. As on many days in the year the ratio of adhesion is unavoidably low, on those days the resulting inconvenience will be confined to the pusher grade, but will be very apt to lead to the permanent cutting down of trains on both grades.

The consequences of any unforeseen breakdown or other cause of accident or delay are so much more serious on heavy grades that a certain excess of motive-power is naturally sought for and generally obtained in such localities, sometimes at the expense of sound economy.

The curvature on heavy gradients is usually very much more severe. As the speed is also, usually, very much slower, and complete stoppage from lack of power more frequent, it appears probable (pars. 308, 335) that the curve resistance per ton is higher, and hence that either the rate of compensation for curvature must be made higher on high pusher grades or a lower average rate of grade than a nominal balance requires be adopted.

THE DUTY OF ASSISTANT ENGINES.

767. Under the ordinary exigencies of operation, with two important exceptions, below noted (par. 770 *et seq.*), pushing or assistant engine service must be rendered by separate engines, specially detailed for that duty and available for no other. It is therefore not correct to assume that the pushing service will cost about the same per mile run as for through engines, or that pushing engines will make the same annual mileage. Rather, the safer basis is to assume as nearly as may be that a certain number of engines must be maintained for that service alone, at a certain cost per day regardless of mileage made, *plus* the extra cost due to running a certain number of miles, whether that number be 50 or 100 or more miles per day.

768. As a general and safe rule, the mileage of assistant engines may be taken at 100 miles per day *if they will have a chance to run it,* and as at least equal to, if not considerably in excess of, the mileage of ordinary through engines. As much as 130 miles per day is run by pusher engines

on various roads, under favorable circumstances, but experience does not justify an assumption that more than this is practicable. If, therefore, the estimated traffic will require 150 miles per day of pusher service, the only safe basis is to assume that two engines with two crews will be required, making 75 miles per day each. Theoretically, one engine with two crews might do the work, but practically, if the duty were too much for one engine and crew, convenience would almost certainly require and justify keeping two engines in working order with steam up for at least 12 hours per day.

When the pushing service to be performed is over 200 miles per day the only safe basis is to assume one engine for each 100 miles, or fraction thereof over fifty.

769. From one to two months of every year is lost by engines while in shop for repairs (see Table 51), which reduces the apparent mileage per engine per year (and hence per day) by 10 to 16 or more per cent; but this loss need not be considered in computing the number of engines required for pushing service from the probable mileage to be run, or its cost, since the cost of these repairs is included in the cost of the miles actually run, and the engines actually detailed to pushing service can and will be always in working order.

The exceptions to which the preceding general rules do not apply are these:

770. 1. When traffic is very light, pusher grades, if not too long, may be operated by cutting trains in two, leaving half the train at the bottom of the grade, placing half of it on a siding at the top, returning for the other half, which is preferably pushed up, and then proceeding, after coupling up, with the entire train once more.

This is done to only a limited extent as a regular practice, although it is a resort in emergencies on nearly all roads. It might well be done to a much greater extent than it is, if it were only to run a freight train three times a week instead of daily. It is one of those possibilities of economy which are neglected until necessity compels them, because they take some trouble and some deviation from ordinary routine in management.

Convenience requires that there should be a siding at least half a train long (preferably, of course, a full train long) at both top and bottom of the grade, the lack of which is no doubt one great reason why this expedient is not oftener resorted to.

771. 2. At short pusher grades near stations, yard or switching engines can often perform a part or all of the required pushing service at very moderate cost—or, what amounts to the same thing, the pushing engines can be so utilized for switching service as to greatly reduce the cost and inconvenience of using pushers.

The instances are many where yard engines are utilized in this way, if only to help trains through yards at which there would be no difficulty, except for the fact that it is a yard, because, for obvious topographical and commercial reasons, it is very common to find large yards near short stretches of objectionable gradients. When the yard is very large, so that several yard engines are constantly employed, the pushing service cannot be assumed to be added without adding its full *pro ratâ* to the number of engines, but in all cases the cost and inconvenience of the service will be decreased, and so, indirectly, the number of engines which will probably be required for the joint service, to the extent perhaps of 15 or 20 per cent of the whole number of engines. Switching engines of the ordinary type, having all their weight on drivers are not well adapted for pushing service, on runs of over a mile or two, nor much used therefor, since they are ill adapted for high speed, which is often desirable in returning down hill.

772. The convenience of the service must be considered as well as the theoretical requirements in estimating both the probable duty and probable cost of the assistant-engine service, as also of course in laying out the grades. Unless a station be situated immediately at the foot or top of the grade, the service must be assumed to begin at the nearest considerable station, if there be one within three to five miles of either point, because that is where convenience will require that it should begin in practice.

Unless two successive pusher grades are more than five or perhaps even eight miles apart, they may more prudently be taken as one and the same grade, because in practice that is the way in which they will be likely to be operated. The tendency is always to consider convenience in such matters, even at the expense of economy; and it may be questioned if there is even a theoretical economy in breaking up a pusher run into two for less than a five-mile interval, or even under special circumstances, with thin traffic, for considerably more. The inconveniences of stopping and starting and of maintaining the double service and the loss of time are too great. No stop is required at the top of the grade for uncoupling the pusher, but for coupling on a stop is necessary, and a single stop of a heavy train costs more than a five- or even ten-mile run of a light engine, which would otherwise be standing idle with steam up.

773. In considering the question of the probable duty of assistant engines it is further to be remembered that trains do not come at equal intervals of time apart, but some are likely to come so near together that two or more engines will be almost indispensable at certain times of the

day, and some so far apart that much time will be lost while under steam. On the other hand, good time can generally be made down hill; and the systems of automatic and other block signals have now been brought so near perfection that short sections at least can be so protected that little time need be lost between trains for the sake of allowing a margin of safety in time.

American railways are but beginning to avail themselves of these interlocking and signal devices, the use of which may be expected to materially increase hereafter. For sections on which pushers are used they are particularly well adapted. At such points the number of trains is practically doubled, and it may well be a question between such signals and a double track.

For any considerable traffic a telegraph station at top and bottom of the grade is all but indispensable.

THE COST OF ASSISTANT ENGINES.

774. This may be divided into three elements:

1. *Interest charge on the original cost*, special to the use of pushers, including extra engines, engine-houses, if any; sidings; block signals, if any; etc.

2. *Cost per day* for wages and a certain portion of the fuel and repair charge all of it independent of the mileage run per day, as is also the cost of maintaining block signals, if any.

3. *Cost per mile run* for fuel and repairs, and for wear and tear of road-bed, track, and sidings.

775. When, as will usually happen, an approximately fair mileage can be obtained from the assistant engines, say 80 to 100 miles per day, it is unnecessary to separate these items from each other, but the whole cost per mile run, exclusive of maintenance of way and interest charges, may be assumed not to vary materially from that of ordinary through engines, unless there is some considerable difference in weight.

The experience of the Philadelphia & Reading Railroad indicates that the intermittent service of pushing engines does not add materially to expenses, and much other evidence to the same effect might be given, as also for the fact that assistant engines will realize a somewhat higher yearly service than through engines, owing to the nature of their service, which facilitates care and prompt repairs. At least the difference in cost, if any exist, must in general be trifling. Assuming there were none at all, the DIRECT RUNNING EXPENSES for fuel, oil, and water, repairs and engine-

wages would average, as per Table 80, page 179 (see Chap. V. for further details), 20.8 cents per mile.

776. The MAINTENANCE-OF-WAY expenses must also be estimated at a considerable figure. There is a peculiar temptation in this case to fall into the error discussed in par. 125, and assume that, except in the one item of wear of rails, there will be little additional expense for maintenance of way; but partly for the indirect causes discussed in par. 125—the necessity of maintaining a higher standard as trains increase, as well as of keeping up to the same standard—the cost of maintenance of way will certainly be materially increased. For reasons which may be readily deduced from pars. 717–18, it will certainly not be excessive, and probably as nearly fair as is possible, to assume that the whole cost per train-mile of maintenance of way, excluding maintenance of bridges and buildings, is increased about 50 per cent by the pusher directly, and including the indirect increase due to heavier traffic may fairly be taken as in practice 100 per cent.

777. The total cost of pusher service (including the return light down grade) PER MILE OF INCLINE (on the basis of $1.00 per train-mile average cost) will then be as follows:

Direct running expenses, fuel, water, oil, repairs, and wages per mile of round trip..................................	41.6 cents
Maintenance of way expenses per mile of round trip 17.5 cents (Table 80) × 2..	35.0 "
Total cost per mile of incline per round trip................	76.6 "

Or per year per daily train per mile of incline, $0.766 × 365 = $280.00.

778. The introduction of steel rails and the general cheapening of all railway supplies has greatly reduced within recent years the cost of such service, especially for maintenance of way. In the former edition of this work this expense per mile of round trip was estimated at 94 cents, of which 54 cents were for locomotive expenses and 40 cents for maintenance.

779. This estimate assumes that the pushing engines are kept fairly busy, so as to make something like 80 to 100 miles per day average mileage. If this seem impossible or doubtful, it will require to be increased correspondingly. All that the engine falls below 100 miles per day, i.e., all potential mileage not actually run, may be assumed to cost ½ to ⅓ as much per mile as if it had been run, and is so much added to the cost of what is run.

780. This results from the following estimate: Comparing the cost per mile run of an engine in actual service, as per Table 80, and the cost

of an engine standing still in the yard with steam up for an equal period of time, we have, approximately, the following:

	Average in service, cts. or p. c.	Standing in yard. Per cent.	Am't, cts. or p. c.
Fuel,	7.6	10	0.8
Oil and water,	1.2	0	...
Repairs,	5.6	10	.6
Wages,	6.4	100	6.4
Maintenance of way,	17.5	0	...
	38.3		7.8

781. The chief loss from standing still is in ENGINE-WAGES. FUEL is not necessarily wasted to any such extent as to make it an item of importance. The total consumption per hour of an engine standing in the yard to simply make good the loss from radiation has been determined by experiment not to exceed necessarily 24 to 35 lbs. of coal, or about the quantity burned in service in running one half-mile. This would indicate that the consumption of an engine standing idle in a yard for a whole day with steam up would only be one or two per cent of what it would be in service; but an engine standing idle only between intermittent periods of service would, by carrying a larger fire and the cooling off of the machine, as well as by blowing off through the safety-valve and other effects of careless firing, waste much more than this proportion; so that the allowance made above (10 per cent) is hardly too high.

782. The effect on COST OF REPAIRS per mile run of intermittent work is likewise slight. There is no doubt some bad effect from the intermittent and irregular nature of pusher service, but the mere fact that an engine, between its trips, stood idle with steam up for an hour, more or less, instead of immediately starting off on another trip, would of itself add little to the cost of repairs per mile actually run. Deterioration would no doubt be going on, but all the great causes of deterioration—wear and tear of running gear and machinery, from stopping and starting, brakes and running over the track, injury to boiler and boiler-tubes by cooling off, by the fierce heat of the fire and by the mechanical action of the coal drawn through the tubes, etc., etc.—are absent. The above allowance is therefore ample, and probably excessive, leading to the resulting conclusion, that the cost of an engine per hour standing in the yard with steam up is little more than one fifth as much as if in motion at 15 or 20 miles per hour.

The correctness of this conclusion might be indicated in another way

by comparison with experience with switch engines, but more detailed comparison would lead us too far.

783. The interest charge on pusher engines is fairly chargeable to the cost of the service as well as the running expenses, for the same reason that the interest charge in the extra engines required to operate a heavier grade must fairly be added to the other expenses entailed by the grade, as specified in par. 721. Properly speaking, the first cost of these extra engines is a part of the cost of constructing the line of those grades, as much as the bridges or track thereon, and it should be included in the estimate of the cost of construction unless the interest charge is added to the operating expenses.

784. To accurately estimate the cost of pusher service, then, we must determine—

First. The length of pusher run in miles (par. 767).

Secondly. The probable number of daily trips per engine, and hence the number of engines required for the given traffic.

Thirdly. Determine the annual interest on their first cost.

Fourthly. Compute the cost of the mileage made, according to pars. 777 and 780.

The sum of the last two items will be the total cost of the pusher service.

COMPARISON OF PUSHER-GRADE LINES WITH UNIFORM GRADIENTS.

785. Ordinarily, when pusher grades are used, they will not be perfectly balanced with the through grades, but either one or the other, whichever opposes most difficulties of construction to obtaining low grades, will be the true limiting gradient. The other must then be assumed, in order to give a fair comparison with a uniform gradient line, to be of such rate as to give a perfect balance (Table 182), although the fact that it is really lower will not therefore be a wholly valueless advantage, even for freight purposes. In Fig. 179, for example, the 0.7 through grade and the 1.75 pusher grade are not perfectly balanced. The pusher grade should either be reduced to 1.65 or the through grade be assumed to be equivalent to 0.75, unless the circumstances make it proper to assume the use of heavier pusher engines than through engines, which is rarely the case (par. 763 *et seq.*).

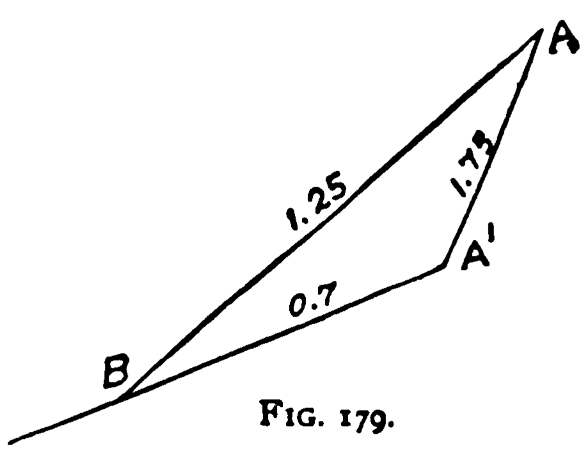

FIG. 179.

786. If, then, we have two alternate locations, *AB* and *AA'B*, Fig. 179, one of which, *AB*, is on a lower through grade (say of 1.25 per cent), which it has appeared practicable to operate without assistant power, and the other, *A'B*, is the lowest through grade which it has been or will be practicable to secure apart from the incline *AA'*, which it is expected to work with assistant power, BY ADOPTING THE LINE WITH ASSISTANT POWER—

First. WE GAIN what is equivalent to a reduction in the ruling grade from the rate *AB*, which in the diagram is 1.25 per cent, to the rate *A'B*, whatever it may be. The amount of this gain will depend upon the skill and good fortune with which the grades have been adjusted, but it will ordinarily be a very considerable difference.

Second. WE LOSE the cost of assistant power on the incline, as estimated according to pars. 777-784.

787. The problem being thus stated, the values previously determined give us a ready and simple method of solving it. Thus if, in Fig. 179, we have estimated the probable number of daily trains required on the pusher-grade line *A'B*, which is actually a 0.7 maximum, but is virtually made 0.75 by the effect of the imperfect balance of the pusher grades, then, by adopting the line having a uniform maximum gradient of 1.25 per cent, we have in effect increased the ruling grade 0.50 per cent. Now, assuming the pusher line to be 100 miles long with a pusher grade of 10 miles length on it, and the other line to be 105 miles long, the estimated difference in the operating values of the two alignments would be as follows, allowing the rate of interest on capital to be 5 per cent.

In favor of the pusher line AA'B, PER DAILY TRAIN:

Difference in ruling grade—a saving of 0.50 per cent increase above a 0.7 per cent grade: Value by Table 178, $3,541 ÷ 0.05 × 5 = $354,000 for a division 100 miles long. For a division 105 miles long we have (par. 740), $354,000 × 1.05 = $371,700

In favor of the uniform gradient AB:

10 miles saved of assistant-engine service, cost by par. 777 $2,800, which, capitalized at 5 per cent, = ... $56,000

Net difference in operating value due to difference in gradients only, in favor of line *AA'B* $315,700

Value of 5 miles of distance in favor of line *AA'B* possibly nothing, and possibly by par. 196, $\frac{\$290}{.05} \times 5 =$ $29,000

Total difference in operating value, per daily train, in favor of low-grade (pusher) line $344,700

To this is to be added an allowance for any difference in the probable traffic, for any loss of time of assistant engines, and for any difference in the probable capital expenditure for locomotives, which will naturally be least on the line which shows the highest operating value.

788. By computing various examples of this kind it will be seen how very large an economy almost invariably results from using pushers, but the condition that the pushers must be kept busy and be always on hand to have them economical must be remembered. The larger the traffic of the road the more easily can this be assured, and consequently the more frequently can pushers be used. They are sometimes used as often as three or four times on a division, but with a light traffic this would be inexpedient.

All the preceding, however, applies to freight business only. The use of pushers in passenger service is far less general (par. 757).

789. Whether for passenger or freight service, perhaps the most advantageous and satisfactory basis of comparison of all for comparing alternate systems of gradients, as it certainly is the simplest, is to determine the number of engine-miles which must be run per through car (or ton)—i.e., per car or ton—moved over the line for the entire distance between termini.

A "car" has become in recent years such a very indeterminate thing, owing to the rapid increase in weights carried, that the ton is the best limit to use, as in Table 170, giving the capacity of engines on various grades.

By this process the effect of differences of distance as well as gradients is included in the same estimate, and having assumed a reasonable price (see Table 143) for the cost of the additional motive-power and train-service required, the estimate is very readily completed.

790. Thus the example already given (par. 787 and Fig. 179) may be compared as follows:

Line *AA'B* for pushers: 105 miles; 10 miles, 1.75 per cent (92.4 ft. per mile), 90 miles, actually 0.7 per cent, but in effect 0.75 per cent. Regular load for through engine with 11 tons on drivers (Table 170), 881 tons.

Line *AB*, uniform gradient: 105 miles, 1.75 per cent (66.0 ft. per mile). Engine load (Table 170), 592 tons.

We then have this comparison:

Line *AA'B*, 881 tons × 100 miles = 88,100 ton-miles hauled by 100 + 10 miles run by engine (in one direction), or 801 ton-miles per engine mile, or $\frac{801}{100}$ = 8.0 through tons per engine-mile.

Line *AB*, 592 tons, through load, no pusher service, or $\frac{592}{100} = 5.92$ through tons per engine-mile.

We have then $\frac{8.00}{5.92} = 35.14$ per cent excess of engine-mileage on line *AB* for the same through traffic, whatever it may be; and estimating the cost of this extra engine-mileage at about half the average cost of a train-mile, as in par. 720 (which is not quite correct, because the excess of *train*-mileage on line *AB* is even greater than the excess of *engine*-mileage) the freight operating expenses over the two lines will be to each other about as 100 to 117.6. Estimating then, however rudely, the operating expenses over either line, we have a tolerably close indication of the difference in value between them, which will lead to almost exactly the same total as in par. 787.

791. With reference to the passenger business on this particular line, if only a moderate through traffic is to be handled, the difference in the gradients will be, with well-arranged stations, a matter of little consequence. If only a little heavy passenger traffic is to be handled, under otherwise favorable conditions, the uniform gradient of 1.25 per cent will have a certain advantage; but if any really heavy passenger traffic is to be handled, the pusher line will have much the same advantage for it, and for much the same reasons as it has for the freight traffic. It is a much more indeterminate problem, but the financial importance of high passenger speeds at all points and the effect upon it of low gradients and easy curvature is generally over-estimated (pars. 757–9).

CHAPTER XVII.

THE BALANCE OF GRADES FOR UNEQUAL TRAFFIC.

792. AN engine which has carried a full load in one direction must return at nearly the same expense, whether the train behind it be fully loaded or not. There must, of course, be the same number of cars in each direction, in the long-run, or very nearly so (there being some lines over which considerable numbers of cars run only in one direction, returning by other routes), and of course there is always precisely the same amount of motive-power available. If, therefore, the movement of traffic is permanently heavier in one direction than in the other, or there is good reason to expect that it will be, the grade opposed to the lighter returning traffic may be made heavier than that in the opposite direction by an amount sufficient to make the resistance of trains, and hence the requisite motive-power, the same in both directions. No advantage whatever results from reducing the return grades below this, beyond the small amount which represents its value for occasional emergencies when the usual balance of traffic is temporarily disturbed, and the still smaller amount which represents the value of reducing the rate [illegible], and hence great economy may [illegible] by utilizing to the [illegible] made possible by [illegible] lighter load in one direction.

793. [illegible] balance of grades. [illegible] The [illegible] the adjustment [illegible] great uncertainty. [illegible] minerals or

other special traffic. For roads of a large and mixed traffic, as even our through East and West trunk lines, the problem is much complicated by the fact that changes of importance, especially in the transportation of minerals or from the construction of new lines, are liable to occur at any time. Thus the growing anthracite coal trade to the West has produced and is producing great changes in the ratio of the tonnage East and West; and not unfrequently on different parts of the same line the burden of traffic is in opposite directions—perhaps from causes entirely beyond foresight when the road was first built. Nearly always the ratio of preponderance varies considerably from point to point.

794. On the Pennsylvania Railroad the balance of traffic is widely different at different points, the westward preponderating greatly at the western end, and the eastward at the eastern end, as shown in Table 184, which is well worthy of study. Table

TABLE **184.**

COMPARATIVE VOLUME OF THE TRAFFIC EAST AND TRAFFIC WEST AT VARIOUS POINTS ON THE MAIN LINE OF THE PENNSYLVANIA RAILROAD, BETWEEN NEW YORK AND PITTSBURG. 1885.

STATION.	Miles from New York.	COMPARATIVE VOLUME OF TRAFFIC (Phila. = 1.00).		Ratio of Loaded Cars.* East to West.
		Eastward.	Westward.	
Jersey City	1	0.51	1.15	1 to 1.47
Trenton	57	0.74	1.13	1 to 2.13
Philadelphia	91	1.00	1.00	1 to 3.26
Columbia	171	1.06	0.92	1 to 3.76
Harrisburg	196	1.17	0.94	1 to 4.09
Mifflin	245	0.98	0.81	1 to 3.97
Altoona	327	0.77	1.10	1 to 2.25
Conemaugh	364	0.72	1.05	1 to 2.22
Derry	398	0.56	0.73	1 to 2.49
Pittsburg	444	0.30¼	1.27	1 to 0.78

* The probability is that *most* of the loaded cars West are more lightly loaded than those East, so that the actual excess of east-bound over west-bound was greater than this table indicates, except at Pittsburg, where the west-bound cars were presumably the heaviest. *The average disproportion over the whole road,* in ton-miles, may be deduced from Table 98 to be 1 to 3.49.

By referring to Table 98 it will be seen that the variation in the disproportion is as lawless in different years as the above table shows it to be on different parts of the same line.

98, pages 232–3, shows the revolutionary way in which this disproportion has varied during the past forty-five years, or during the entire history of the road. Neither the extent nor the nature of these changes could well have been anticipated when the road was first constructed; but from our present stock of knowledge, actual or potential, as to the course of such matters in the past, we may make a reasonable and safe approximation at least to the future probabilities in this respect, by investigating the facts as to neighboring or rival lines. The proper manner of doing this we will shortly consider. A large body of further statistics of the same kind as to other roads might be presented, but not enough to serve any more useful purpose for any particular line than the approximate figures given in this chapter, without an inadmissible amount of them.

795. ASSUMING the ratio of the tonnage in each direction to be known or assumed, the admissible difference of gradients to correspond may be very quickly determined by the aid of the long Table 170, by determining the total load in tons behind the tender which must be hauled on the return trip, for a given disproportion of tonnage. The total load can at once be divided into paying load (freight) and dead load (cars), if we know or assume the average load and weight per car. By 1890, with the prevailing tendency to increase average load, it is probable that the total load hauled in the direction of heaviest traffic might fairly be divided as follows:

	Total weight per car or train.	Live weight per car or train.	Dead weight per car or train.
General Traffic, . . .	1.00	0.60	0.40
Mineral Traffic, . . .	1.00	0.72	0.28

At present this is a little too favorable; not as respects the nominal loads, but as respects the loads actually hauled, although some of our best roads approach it. For example, the average load *of loaded cars* on the Pennsylvania Railroad is now 14 tons, and of East-bound only $15\frac{1}{2}$ tons. The average weight of the empty cars is probably in the neighborhood of $10\frac{1}{2}$ tons. See Table 154, p. 486.

Then if the return tonnage be only half as great, the total weight of return trains will be only $0.40 + \frac{0.60}{2} = 70$ per cent as heavy in tons; and having computed this weight in tons (making also an allowance which

we shall consider in a moment) we find at once from Table 170 the corresponding grade.

796. In this simple manner Table 185 below was computed, which gives sufficient data to enable the proper balance under almost any given conditions to be readily determined by interpolation. Without the aid of Table 170, while each step in the process is simple enough, there are a good many to be taken, in each of which a mistake is easy, which is probably the reason why in not a few instances of actual practice errors of importance have been made in it.*

797. The computation of the theoretical balance of gradients is complicated by the following practical considerations, the effect of which should be included in the computation:

1. The journal-friction of empty cars is at least 2 lbs. per ton (= 0.1 per cent of grade) higher than with loaded cars, requiring a modification of the theoretical balance of grade to that extent in favor of the lightest traffic in case all cars return empty, and proportionately if a part return empty. This has been done in computing Table 185, as indicated by the two lower lines.

2. It is not practically possible (par. 91) to have all cars in all trains always loaded even in the direction of heaviest traffic. A certain proportion of the cars, which for this particular purpose may be estimated (liberally but not unfairly) at from 5 to even (in special cases) 10 per cent, will go empty even in the direction of the heaviest traffic. These cars serve to increase by so much the proportion of the dead to the live load of trains, and by so much diminish the admissible difference in gradients, and so also will the fact that even loaded cars do not by any means average their full nominal capacity. Both of these latter considerations, however, affect only the estimate of the proportion of the paying to the dead load, which is the first thing to be assumed for determining the balance of grades.

798. 3. The disproportion of traffic varies not only from year to year and from point to point, but from day to day and from week to week, as already noted. That this must inevitably be so, more or less, is apparent: Traffic cannot be held until it is convenient to move it, but must be

* E.g., a prominent text-book gives extracts from official reports of two very prominent engineers, each containing a number of computations of this kind, every one of which is much in error, and in quite different ways, as pointed out and corrected in detail in the first edition of this treatise. The writer could readily mention still other instances.

TABLE 185.

PROPER ADJUSTMENT OF RULING GRADES FOR AN UNEQUAL VOLUME OF TRAFFIC IN OPPOSITE DIRECTIONS.

[Correct within an inconsiderable percentage for all classes of engines and conditions of service. Computed for an average Consolidation engine from Table 170, as explained in par. 705. Rolling-friction of empty cars assumed to be 2 lbs. per ton greater than that of loaded cars.]

Grade opposed to Heaviest Traffic. Per Cent.	RETURN GRADES Opposing an Equal Resistance to the Power of the Engine if the Gross Weight of Cars and Load returning is— (Weight in direction of heaviest traffic = 1.00)					
	.88	.70	.64	.52	.40	.28
	Ratio of Return Freight only to that in Direction of Heaviest Traffic.				Freight Cars Returning Empty.	Coal Cars Returning Empty. (See par. 802.)
	0.8	0.6	0.4	0.2		
Level.	[illegible]	[illegible]	.15	[illegible]	[illegible]	0.84
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.14
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.92	1.44
.3	[illegible]	[illegible]	[illegible]	[illegible]	1.14	1.73
.4	[illegible]	[illegible]	[illegible]	[illegible]	1.35	2.00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.27
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.54
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.79
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.03
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.28
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.52
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible] will reduce the ad-

missible rate of return grades by about 0.2 per cent in the "north-east corner" of the table, its effect decreasing very rapidly from that point in each direction.

A LOWER RATIO OF ADHESION (than ¼) will also REDUCE the admissible rate of return grade, its effect being very important in the "south-east corner" of the table, but decreasing still more rapidly in each direction therefrom.

THE USE OF TANK ENGINES will very materially INCREASE the admissible rate of return grades, having a directly contrary effect to a lower ratio of adhesion. The same is true in less degree as the proportion of weight on drivers or ratio of adhesion is increased.

None of these changes being proper ones to assume, it is not deemed necessary to give exact figures.

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moved at once; and since there must be more or less irregular fluctuations in the volume of all traffic, it may well happen, and not unfrequently does happen, that for the time being the burden of traffic shall be in the opposite direction to the normal one. Thus on the leading East and West lines of the United States, especially those of the second grade, it is not uncommon to see engines running East light to handle an unusual quantity of West-bound traffic, although there is normally a very heavy excess of east-bound traffic on nearly all of them.

When this occurs favorable west-bound grades are a decided economy, although ordinarily they may be unimportant.

Nevertheless, the importance of this cause should not be exaggerated. Marked irregularities of this kind are exceptional and short-lived, and would justify but very small expense to reduce grades on their account below what the average requires. Irregularities of 5 or 10 per cent may be expected to exist for nearly half the time, and hence to justify about half the expense for reducing the grades correspondingly that would be incurred to provide for the average condition of the whole traffic. There is also a certain small economy in being able to send back some of the surplus engines and train crews light, as passenger extras.

4. For passenger traffic equally balanced grades are always desirable, as noted more fully in par. 807 *et seq.*

799. It is noticeable that all four of these limiting provisos tend to diminish the admissible variation in opposing rates of grade. In the aggregate they indicate that a reduction of the grades against the lightest traffic by something like 0.2 to 0.3 per cent (10 to 16 ft. per mile) below what the assumed average disproportion in weight of trains seems to require, is worth nearly half as much as if required by the average conditions themselves. When, in addition to these reasons for approximating more closely to an even balance in spite of a known disproportion of traffic, the very existence of the assumed disproportion appears doubtful,

still greater caution should be used in assuming that anything will be unobjectionable but an exact balance of resistances, which latter is of course the safest assumption to make when the future is for any reason very doubtful.

Nevertheless, although the estimates of the probable future disproportion should always, for the reasons given, be exceedingly conservative, it may on many if not on most lines be determined with practical certainty that a certain minimum disproportion at least will exist for the decade or so ahead, which is as long (par. 78 *et seq.*) as the engineer is financially warranted in looking ahead.

800. It is to be remembered also that the same assumed balance of grades which permits the grade in one direction to be made higher requires the grade in the other to be made lower, if possible, so that the assumption of a certain preponderance of traffic in one direction does not warrant any relaxation of effort to obtain low grades, but merely gives it a little different direction. If there be merely a probability that the traffic in one direction will be slightly heavier than in the other, with a possibility that it may be either considerably heavier or evenly balanced, and the same expenditure will substitute grades of 0.65 one way, and 0.55 the other, in place of 0.6 grades both ways, it is good engineering to do this, for we can only strike an average between the maximum and minimum possibilities and act in accordance with the mean. It is demonstrable mathematically, as well as clear to the reason, that this course is as binding upon us as if we had positive knowledge that the mean of our estimates (if they really are such, and not guesses) was the exact truth.

Topographical considerations often make it impossible to even attempt a balance of gradients, at least in the way of favoring the heaviest traffic. It is, however, nearly always possible to favor the expense account in such cases, somewhat at least, by not showing unnecessary favors to the lighter traffic.

801. FOR AN EXCLUSIVELY MINERAL TRAFFIC the expediency of adjusting the grades for the full theoretical difference can rarely be questioned, and it is of course for this traffic that the greatest difference is required. At the present time the ratio of load to weight of car is considerably over 2 to 1, so that less than $\frac{1}{3}$ of the weight of a full train is cars and over $\frac{2}{3}$ paying load. Consequently, the return trains of empty cars weigh less than $\frac{1}{3}$ as much as the full trains, and the proper balance of grades shows a wide contrast in them, as will be seen in Table 185.

802. An important fact to remember in considering an almost exclusively mineral traffic is that whatever general freight business there may be will probably be against the main traffic almost exclusively, and that the consumption of supplies per inhabitant is large in mining regions, and almost wholly imported. The traffic per inhabitant of mining regions, including shipments of machinery, etc., as also the output per miner (about $\frac{1}{7}$ to $\frac{1}{10}$ of the total inhabitants), may be readily estimated by a little investigation. The figures vary too greatly to attempt any general analysis.

803. For general freight business no such difference as with mineral traffic ever exists, but something closely approaching to it exists at times on the leading East and West trunk lines, on which the normal average is only from 3 to 4 tons West to 10 East. It is probable that there will always continue to be a heavy preponderance of East-bound traffic in the United States, although whether it will continue to be as heavy in the future as in the past is a far more doubtful matter. The proportion of export traffic will become relatively less as the population of this continent increases, and this traffic has now a great influence in causing the disproportion of traffic which at present exists. If the East were to continue to be the manufacturing region *par excellence* this loss would be compensated for, but that this will be the case seems very doubtful.

804. An enormous West-bound anthracite coal-traffic, moreover, has sprung up within the last few years which is reducing and will still more largely reduce the existing disproportion. The rise and growth of this traffic is a good illustration of the great changes which may come with time, but which are for the moment not considered. It is the chief cause for the very remarkable reversal of the current of local traffic shown in Table 98.

The only definite fact seems to be that the burden of traffic will always be heavily toward a manufacturing or mining region and away from the shippers of the heavier cereals. Thus it is about three to one from West to East, and about two to one from the Northern to the Southern States.

805. The latter fact shows that it is not safe to say broadly that the burden of traffic is from an agricultural to a manufacturing region; for the South, which is chiefly agricultural, ships to the North, as yet, much less in weight than it receives; the reason being that its exports are largely cotton, and that the current of its commercial business follows a kind of triangular course—from the South to New York or Europe, thence to the interior of the United States, and thence to the South

again. But the rapid development of the mineral resources of the South is bringing about a change in this respect.

806. The possibility of some such roundabout process of exchange as this, especially on a small scale, is one which must be very frequently remembered if a reasonable estimate of probabilities is to be made. Thus, when the Mexican system of railways was projected it became at once important and difficult to determine in which direction would be the largest freight movement. The central plateau is a region of great and largely undeveloped grazing and agricultural possibilities, but on the other hand is a great and largely undeveloped mining region, having no workable coal as yet known. Bearing in mind the character of the regions of the United States to the north, the writer concluded that the traffic would not probably be very unequal, but that the tonnage would be the heaviest northward. This expectation has not yet (1885) been fulfilled, but the direct contrary is the case, the preponderance being very heavily into the City of Mexico, and largely on account of the triangular process of exchange referred to. The products exported are on the coast or seek the coast, and thence by very indirect channels pay for the shipments (as yet small) which go to Mexico in return by rail. Whether or not this tendency will continue is doubtful. Probably it will not, but the burden of traffic will be out of Mexico when a fuller development has come. In any case it illustrates the necessity of looking beyond the superficial and immediate possibilities, and remembering that great changes may come with time.

807. For passenger service grades should in all cases be equally balanced, because whether passenger cars be loaded or unloaded makes but an inconsiderable difference (par. 606) in the weight of trains, even if it were not certain that passenger travel must be, in the long-run, equal in each direction, in spite of a temporary preponderance in one direction, due to emigration. Therefore, in proportion as the passenger traffic is a larger and mineral traffic a smaller element, and in proportion as the preponderance of freight tonnage is doubtful, the expediency of seeking uniform grades in each direction increases.

808. It follows also, that when an unequal freight or mineral traffic exists, combined with a considerable passenger traffic, there is always a certain advantage, and hence a certain justifiable expenditure, in reducing the rate of grade in either direction, although the other be left unchanged. The passenger service is always benefited by reducing the higher rate of grade, whichever it may be (provided it is, for passenger service, a *de-facto* ruling grade, as explained in par. 407); and after

this has been done there is a certain advantage *to the freight traffic only* in reducing the grades against the heaviest traffic. The admissible expenditure for doing this is only that appertaining to the particular traffic benefited.

809. For example, suppose the grades on any line to be 1.00 and 1.20 per cent (52.8 and 63 ft. per mile), and the ratio of the weight of freight in each direction to be about as on the Pennsylvania Railroads, viz; as 1.0 to 0.3:

	Per cent.
Well-adjusted grades for freight service would be (Table 185)	0.6 and 1.2
Well-adjusted grades for passenger service would be	1.0 and 1.0

We can properly expend, therefore, to reduce the grade which limits the freight traffic (1.0 per cent) to 0.6 per cent, as much as the freight traffic alone justifies; and to reduce the grade which is heaviest for passenger service (1.2 per cent) to 1.0 per cent only as much as the passenger service alone justifies, which, in case of a light local passenger business, will not be much (par. 732).

810. Even if the business of a road consists of three distinct classes of traffic, passenger, freight, and mineral, each one of which would require a different balance of ruling grades, this difference need introduce no confusion in the estimations of the value of reducing grades, for we have only to determine from Table 185, what class or classes of traffic any proposed reduction of grade will be valuable or worthless to, and the justifiable expenditure to reduce it may be determined for that traffic only by the methods of Chap. XV., par. 726 *et seq.*

811. It may also be noted that a mineral traffic should in general be considered simply as a part of the general freight traffic. It is only under peculiar circumstances, as when the haul is short or the mineral traffic is very large, that they should be separately considered, and never when their separate conduct would involve a large wastage of motive-power or of empty car-mileage, in either direction, since the two can always be combined together, light freight trains being filled up with coal cars or *vice versâ*, as is now done on the trunk lines. It has even come about that empty grain cars returning West are filled up with coal so as to go loaded in both directions, and this tendency may be expected to increase or prevail whenever it will save a considerable movement of cars in opposite directions, since it effects a very large economy.

812. A heavy tonnage goes into all cities, since they consume much and produce nothing except in the form of manufactures, which for the

most part weigh much less (although they pay much more) than the raw materials which are shipped for producing them.

813. The exact balance of grades for the traffic becomes easy in the case of a line already in operation, and this should be the first step in studying contemplated improvements, since it may save the necessity of improving the grades in one direction, or at least some of them.

814. The lines of few existing railways have been studied during construction with this end in view. Some of the earlier lines come the nearest to it; for example, we may take three of the most sagaciously located lines in the United States—the Baltimore & Ohio, the Pennsylvania, and the Erie. The Baltimore & Ohio mountain grades have been laid out to some extent with this end in view, since they have 2.2 per cent grades (for 16 miles) opposed to West-bound traffic and only 2.0 per cent opposed to East-bound, but this difference is far less than the disproportion in traffic would warrant, the balance for 2.0 per cent with a disproportion similar to that of the Pennsylvania road (Table 185) being about 3.2 per cent. This, however, is the less important on such a line, because the heavy grades are so long that the trains and motive-power can be adapted quite accurately to each other, as they are in fact, on each separate grade. Using two pushers on the 2.0 per cent grade, and only one on the 2.2 per cent, moreover, would about equalize them for such a disproportion, although it is only on grades of some length that two pushers can be advantageously used. The gradients of the Baltimore & Ohio, considered as a whole, are admirably adapted for cheap working, in spite of their heavy rates, from the fact that they are all "bunched" in one locality. At Piedmont is one of the largest yards in the world, and all trains are made up anew there.

815. The Pennsylvania road has 1 per cent grades opposed to East-bound traffic. The weight of cars and freight westward being by Table 184 about 1 to 0.4 in the neighborhood of Altoona, a correct balance of grades would be by Table 185 about 1.6 per cent. Actually it is 1.8 per cent, and the traffic is worked with one pusher eastward and two pushers westward.

816. The Erie is at two or three of its leading summits a good instance of well-balanced grades, which is not the least of the striking merits of the line. Even without allowing for the early date at which it was built, the consummate engineering skill with which it was carried through the mountains and the primeval forest, without the aid of maps and without a single tunnel on its line (as it then was; one has since been built at Jersey City), with very low grades, and on very nearly the best line which could now be selected, must ever excite admiration. Nevertheless, the Erie and its branches afford several examples of ill-adjusted grades, but it will be more profitable, as well as more just, to consider the instances on its main line where they have been carefully adjusted.

817. The Delaware Division ascends eastward out of the Susquehanna Valley on a 60-ft. (1.14 per cent) grade for 8 miles, thence descends on a

57 ft. (1.08) and 49-ft. (0.93) grade for about 7 miles to Deposit, and thence follows an unbroken descending grade of 10 to 15 ft. per mile to Port Jervis. The curvature probably increases the equivalent grade to about 0.35 per cent. Now, in descending eastwardly from the summit the low rate attained is attained only by following down the hill-side at an elevation of 40 or 50 ft. above the bottom of the valley for nearly the whole distance, with much curvature—about one mile more of distance and at least twice the cost for construction which would have been necessary for a line located in the bottom of the valley on a grade of 1.2 or 1.3 per cent. It would have been most natural, therefore, under all the circumstances, to have chosen the light line; but let us consider the consequences to the light trains returning. As the grades are now, a single pusher engine will just suffice to pass a fully loaded west-bound train over the hill, the balance being (Table 185) 0.35 and 1.03. Had the grade been any higher, the capacity of West-bound engines over the whole division would have been cut down in proportion. It was plainly the intent of the engineer, therefore,—for it is but just to give him credit for the foresight which his work indicates,—that East-bound trains should be taken to the summit from Susquehanna as a separate matter, leaving all the remainder of the division, for trains in both directions, exceedingly favorable. As a matter of fact, trains are taken up from Susquehanna with two pushers.

818. On the Eastern Division, at Port Jervis, a different adjustment has been used, the grades against East bound trains being 46 ft. and against West-bound 60 ft., which is approximately a correct adjustment for enabling trains with pushers to run over the hill with equal loads each way. The remainder of the division is not a very good specimen of location. Some improvements in recent years have been made in it, but it is questionable if a radical reconstruction of the entire division would not prove immensely profitable. On the Buffalo and Western divisions also, and on many of the branches, ruling grades were made the same each way at considerable expense without any adequate compensating advantage.

819. Examples of badly adjusted grades on other lines might be multiplied almost indefinitely, but it would be to little purpose to do so. When the grades are long, considerable leeway in rate may be taken by assuming that the grade will be separately operated, but with short grades of 4 to 6 or 7 miles this is not expedient.

CHAPTER XVIII.

LIMITING CURVATURE AND COMPENSATION THEREFOR.

820. UNDER three different conditions curvature may come in, in advance of gradients, as a limiting agent to fix the weight of trains:

1. When curves are introduced on a maximum grade without reducing the rate of the latter by what is called the COMPENSATION FOR CURVATURE, so as to keep the aggregate resistance constant on both curves and tangents.

2. When a line is nearly or quite level, and yet runs through a region requiring much curvature which (as is very apt to happen on such lines) cannot be "compensated" because there are no grades, or no sufficiently high grades to reduce, in order to eliminate their additional resistance.

3. When on lines of the latter (or any other) class curvature of such short radius is used as to limit the length of trains more than would the same amount of curvature with longer radii.

These causes are more or less interrelated with each other, but we will consider them separately, so far as may be, in the order mentioned, summarizing our conclusions at the end of this chapter (page 632).

821. We have seen (par. 335) that curve resistance varies from less than 0.5 lb. per ton to perhaps 2.0 or even more lbs. per ton per degree of curve, according to circumstances; which at 2 lbs. per ton for each tenth of grade (par. 382) is equivalent to from 0.025 to 0.10 per cent of grade per degree. Assuming, therefore, a "straight" (uncompensated) 0.5 per cent grade, Fig. 180, with alternate equal lengths of tangent and 10° curves succeeding each other, and assuming that the curve resistance is (see par. 834 below) at the rate of 1 lb. per ton, the effect of the curve resistance is in effect to double the grade on the curves, so that the

curves and grade together make the equivalent grade a succession of 1.0 and 0.5 per cent grades, as represented by the dotted line of Fig. 180.

Such conditions have precisely the same deleterious effect, no more and no less, that a long tangent grade-line would have if broken up in similar fashion.

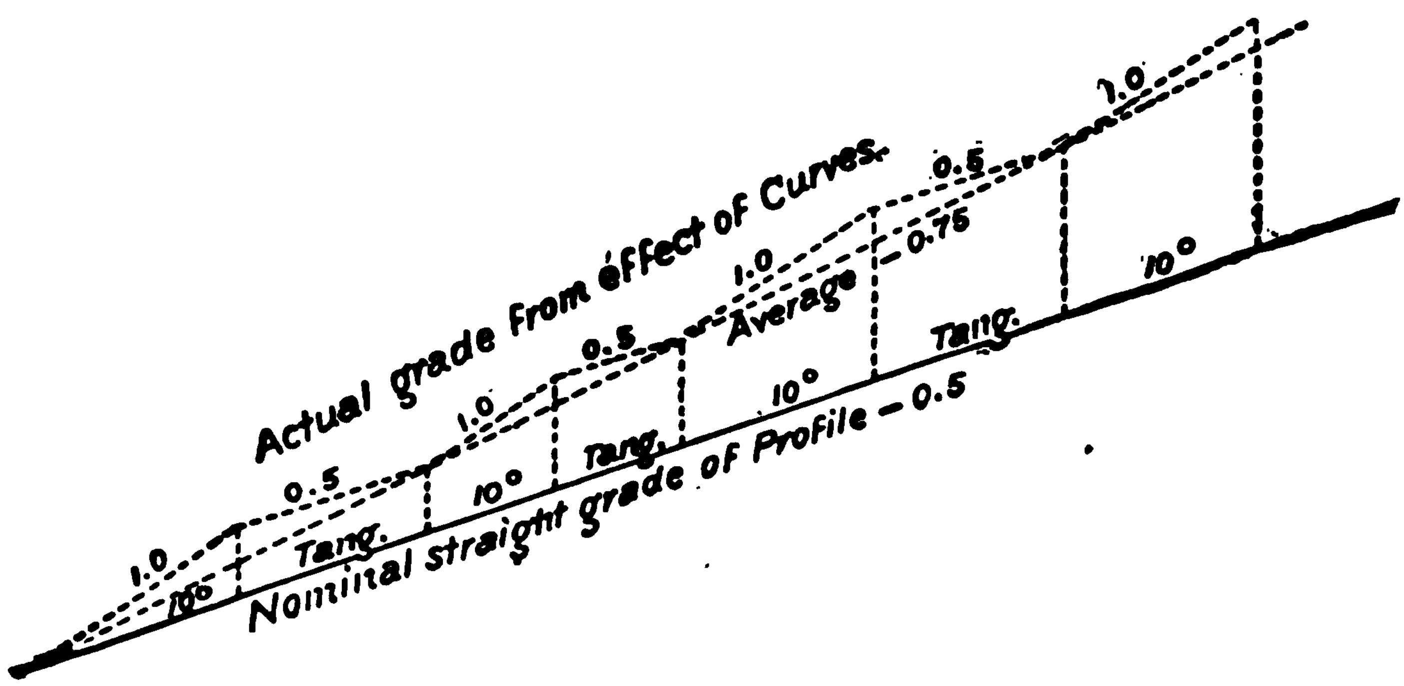


FIG. 180.—EFFECT OF UNREDUCED CURVATURE TO REDUCE GRADES.

822. An immense portion of the heavy grade-mileage of the world has been constructed in precisely this way, the grade being carried through at a uniform rate over curves and tangents alike. Until within recent years nearly all American railways were so constructed, and when the curves were compensated at all, low rates of compensation (0.02 and 0.03 per cent per degree) were and still are chiefly used, for which indeed much can be said (par. 834 below), although in general a less rate than 0.05 cannot be regarded as good practice.

823. The practice of reducing grades on curves appears to have been first introduced on the Continent. American engineers soon followed. English engineers have neglected and still do neglect it very generally. In no part of the world is it universal, many prominent roads in this country having neglected it wholly; as, for instance, the Erie, Boston & Albany, Baltimore & Ohio (for the most part), Pennsylvania (for the most part), and in recent years such lines as the Cincinnati Southern, Chesapeake & Ohio, most of the Denver & Rio Grande, and a host of other lines.

824. The argument by which a neglect to reduce grades on curves has been justified, when any attempt at all has been made to justify it, is that the resistance is AVERAGED BY MOMENTUM so that the broken grade-line of Fig. 180 is reduced by the equalizing effect of slight fluctu-

ations of velocity to the continuous 0.75 grade-line shown below it. The general principle upon which this argument is based is a sound one, to the extent that under favorable conditions precisely that effect may result, either on actual irregularities of grade, or on equivalent ones caused by unreduced curvature. It is not true at all that any injurious effect upon the train, or any increase of virtual gradient, necessarily results from the gradient like the broken line in Fig. 180 in place of the straight 0.75 grades, *under certain and proper conditions.* Why and how this is so, and under what conditions, has been so fully discerned in Chap. IX. (par. 397 *et seq.*) that it need not be repeated, further than to say that a curve may be considered as adding simply so much to the grade, and the two cases be treated alike.

825. But conditions justifying the assumption that unreduced curvature can thus be made harmless by the effect of momentum cannot exist on any actual maximum grade, unless by some rare accident, and consequently it is a rule which should be regarded as of universal application, and rigidly adhered to, that unreduced curvature should under no circumstances be permitted on the maximum grade, and that the reduction should in general be ample, especially near stations and where there is an excessive resistance. The reasons for this are three, as follows:

1. The distribution of curvature even on a grade-line only a few miles long naturally tends to become unequal. Instead of being equally distributed, as assumed for merely illustrative purposes in Fig. 180, it is far more likely to be concentrated in masses of perhaps several hundred degrees of almost continuous curvature, with long intermediate stretches of much better alignment, giving, if such curvature is not reduced, an equivalent profile more like Fig. 185, from which it is far more difficult to obtain a straight "virtual" profile (par. 398) by fluctuations of velocity than with a more even distribution of curvature; and when such excess of curvature comes well up toward the top of a long grade it becomes under most circumstances practically impossible to do so.

826. 2. Even if the curvature be tolerably evenly distributed, the speed on maximum grades is, with the full train which good operating management presupposes, necessarily slow. With extra heavy car-loads or in unfavorable weather—wet, frosty, misty, very cold, or windy—it is necessarily very slow. At what point on the line the most unfavorable conditions will be encountered (for there are always slight variations, from wind or differences of track if nothing more) cannot be exactly anticipated, but on the top of long grades, especially, it can be anticipated with confidence that a very slow speed, not exceeding 10 or 12

miles per hour, will be rather the rule than the exception. At such speeds, and especially at still lower speeds, there is every reason to believe that the curve resistance is greater (pars. 308, 335), while there is no available momentum to overcome it. A train moving at 10 miles per hour (Table 118) has only 3.55 ft. of "velocity-head." At a compensation of 0.05 per degree (1 lb. per ton) 70° of curvature will destroy this head completely, since at that rate of compensation each 20° of central angle destroys one foot of vertical head. In other words, a train moving at 10 miles per hour, which could just continue that speed on a tangent, would be stalled at once by seven stations of 10° curve, or, if by good luck not stalled, its speed would be reduced so low that additional journal-friction (par. 640 and Appendix B) as well as (probably) additional curve-friction would come in and ensure stalling on any closely following curve.

827. 3. Stopping of trains on grades from accident or otherwise is not unfrequently necessary, and then it is entirely clear that a stoppage on a long unreduced curve is a disastrous disadvantage, especially if it be on a long succession of curves so as to forbid the expedient of backing down off the curve to get a fair start. It is then strictly true that it is the grade at that one particular point which is the limiting gradient, and that we cannot strike an average with lower tangent grades before and behind, and assume it is the same thing as if we actually had a uniform average resistance at all points.

828. The rule that a grade-line should be unbroken by unreduced curvature is still sound, in spite of the fact that there are certain circumstances under which slight and short SAGS BELOW THE GRADE-LINE may be introduced to save expense of construction, especially where economy in first cost is a great object, as it is so much more often than is realized during the period of construction. A sag below a grade-line and a rise above it—which is what an uncompensated curve in effect introduces—are two entirely different matters.

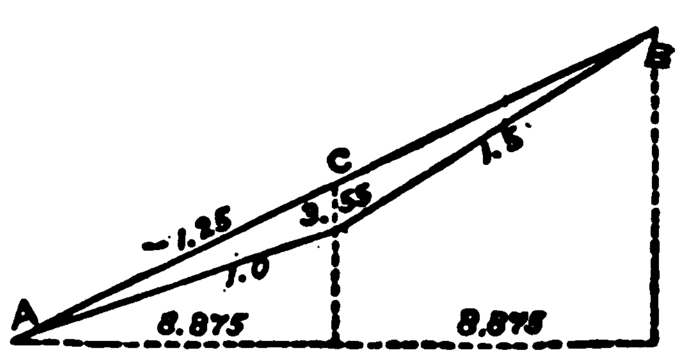


Fig. 181.

Thus, if we have a 1.25 per cent maximum grade, up which a train can just make its way at a uniform speed of 10 miles per hour, a rise of 3.55 feet above the grade-line will, as we have just seen, stall the train. On the other hand, a sag in a grade-line of an equal amount, as at *C* in the grade-line *AB*, Fig. 181, not only does not endanger a stall, but actually

increases the velocity of passing from A to B. For by assumption we have at

A, velocity of ten miles per hour = (Table 118) vel. head of 3.55 ft.
B, " " " = " " 3.55 ft.
C, vel. head of $3.55 + 3.55 = 7.10$ ft. = (Table 118) a velocity of 14.14 miles per hour.

829. Then by the laws of accelerated and retarded motion (see par. 371 or any text-book on physics) the average speed between A and C and C and B as well, and hence between A and $B = \frac{10.00 \times 14.14}{2} = 12.07$ miles per hour—a gain in average speed of 2.07 miles per hour, or about 3 ft. per second in passing over the sag shown in Fig. 181, the comparative times being about 2 m. 0 sec. and 1 m. 40 sec.

This gain of time is for the same reason that a body descending from A to B, Fig. 182, over the different paths a, b, c, d, although acted on by the same force (gravity acting through CB), takes a very different time for descending to B, the cycloid d being the "curve of quickest descent." The resulting velocity at B is in all cases the same, barring loss by friction, but the time consumed in reaching B is widely different.

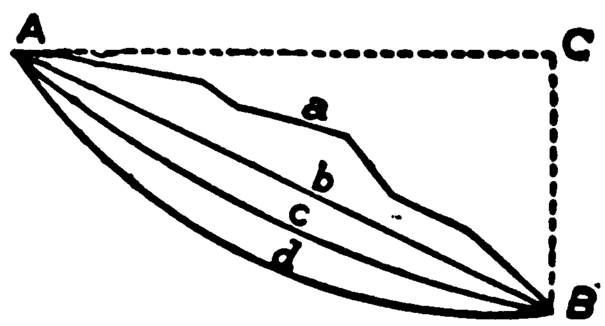


FIG. 182.

830. Therefore, while compensation for curvature should never be omitted, it may still be admissible, in certain exceptional cases (as to temporarily save large fills or otherwise reduce works), to introduce a sag below a grade-line, which is never the case with a rise above a grade-line. Thus the dotted profile, $bbbb$, Fig. 183, can certainly be operated under any and all circumstances (if the sag be not too great, par. 435 and Table 121) as a virtual grade of the same rate as the average actual grade; but with the grade-line $aaaa$ this is not possible, unless the initial speed be very high or the points aa rise but little above the average grade-line.

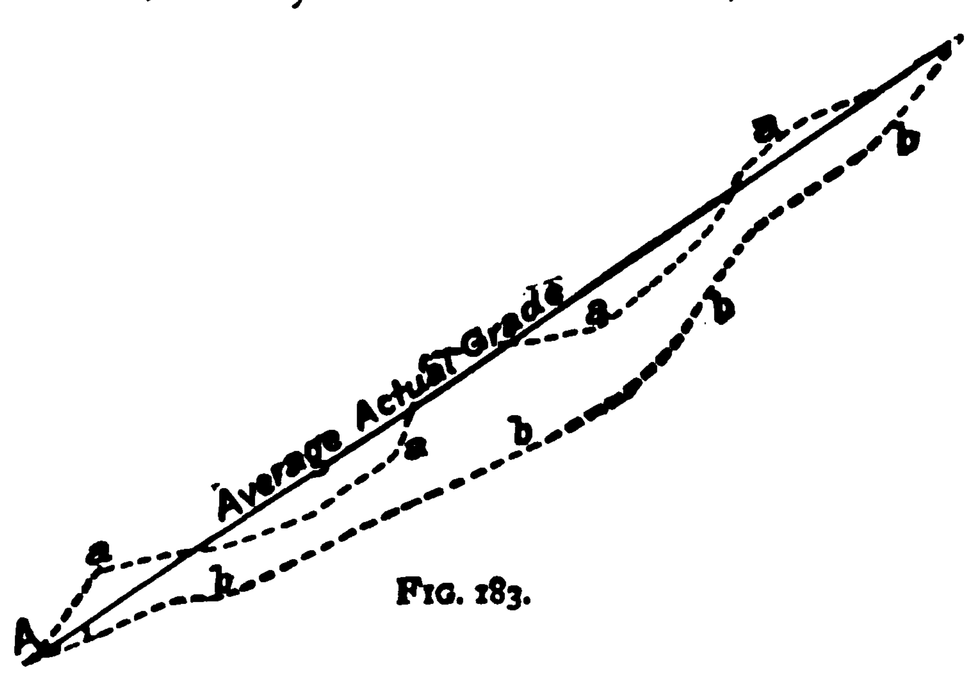


FIG. 183.

831. The principle is the same as the one so familiar to hydraulic engineers known as the "hydraulic grade-line." If water is to be conveyed from a high reservoir to a lower point of delivery, it is an axiom in hydraulics that any liberties whatever can be taken with the grade of the pipes without affecting the discharge in the least, more than the same increase of length and curvature would do in a pipe laid to a uniform grade, provided the pipe at no point rises above a straight line connecting the points of supply and delivery, which is known as the "hydraulic grade-line," as on the line *bbbb*, Fig. 183. If, however, the pipe rises above this line, by however little, as at the highest *a*, Fig. 183, the discharge will immediately be reduced to correspond with the new hydraulic grade-line passing through the point of supply and tangent to the now highest point on the pipe.

In theory a 10-mile grade of 50 ft. per mile might be broken up into (1) 5 miles of level and (2) 5 miles of 100 ft. per mile, without increasing the *de-facto* ruling grade above 50 ft. per mile; but we cannot reverse the orders of these gradients, making the first last and the last first, without a theoretical as well as practical increase of the gradient to 100 ft. per mile. Even in the former case, the velocity at the end of the first five miles of level would have to be 87¼ miles per hour, assuming an initial velocity of 15 miles per hour. This is hardly a practicable speed for freight trains; and it therefore should not be understood that any considerable sags below a grade-line are admissible. The only assertion made is that, ASSUMING such speed to be practicable, even 250-ft. sags below a grade-line would do no harm, whereas any rise whatever above it would destroy it, theoretically as well as practically.

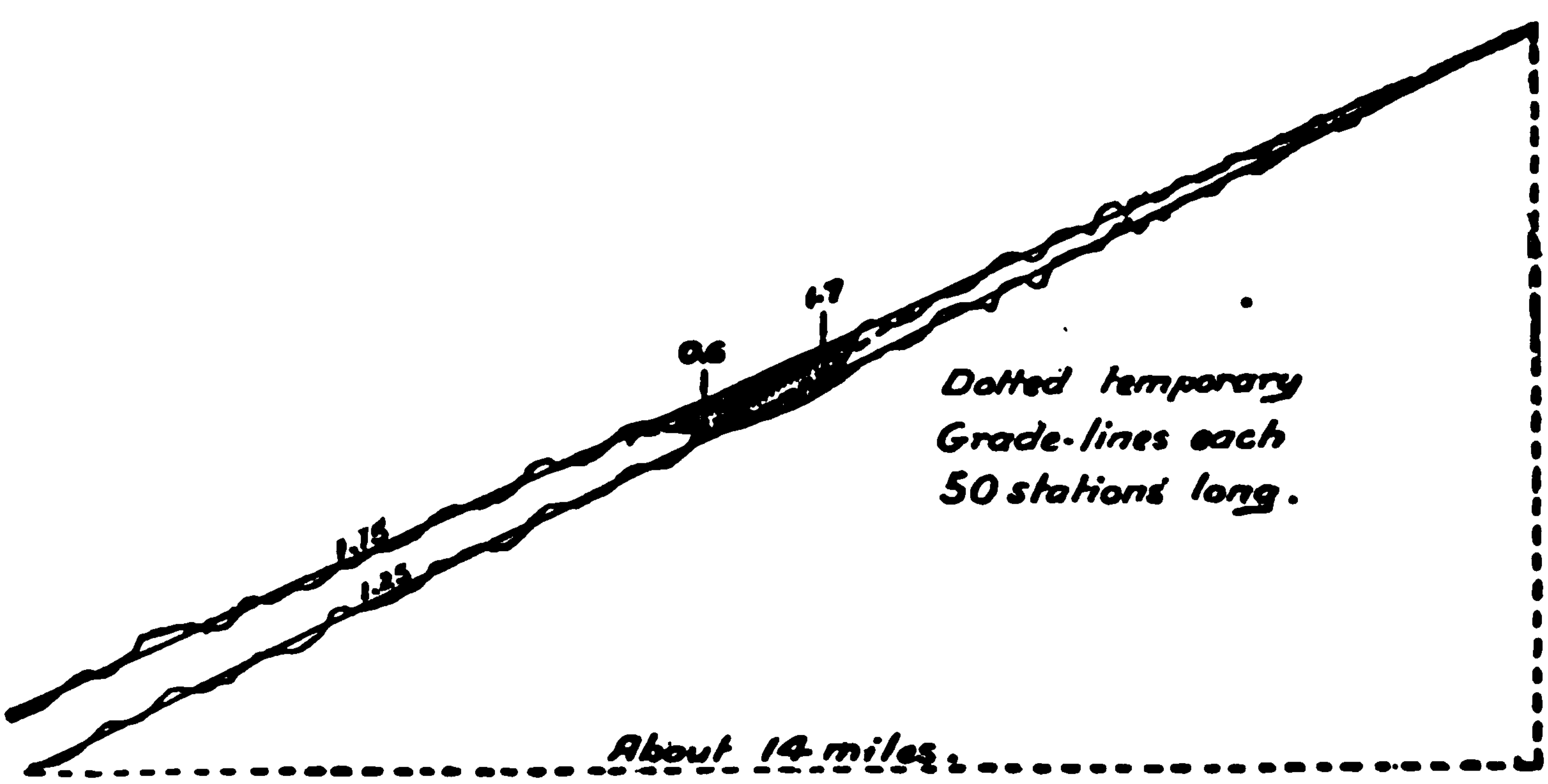


FIG. 184.

832. A remarkable instance of the advantage thus to be gained at times occurred in the writer's practice, and is shown in Fig. 184. Near

the middle of a long grade-line which it was very desirable to keep down to the lowest limits, occurred a saddle between two hills, where supporting ground was wholly lost. Consequently, although there was no material difference in the profile at any other point, both being side-hill, at this point any lift of the grade-line meant so much addition to the fill. To bring the grade-line down to within a few feet of the surface meant an increase of the pusher grade from 1.15 to 1.25, equivalent to an increase of ruling grade on a long division from 0.4 to 0.5. To obtain the lower grade required a very long fill, containing some 190,000 cubic yards when fully made (estimated to cost 20 cts. per yard); but by introducing a sag in the grade-line of some 25 feet (shown by dotted lines on Fig. 184), assumed as about the extreme depth of sag which it would be proper to attempt to operate as a continuous virtual profile, even temporarily,* the fill could be reduced to some 30,000 cubic yards, leaving the track to be gradually raised up to the straight grade-line when and if necessity should appear and convenience serve. To make the fill in the beginning was not justified by the financial status of the company, nor by the time at its disposal, nor could material be obtained at reasonable cost except by train.

833. There were then three possibilities, besides that of making the fill complete:

1. That the grade would continue to be operated indefinitely as a virtual straight grade by the aid of momentum, tolerating the necessary velocity of 30½ miles per hour in the bottom of the sag.

2. That the fill would be raised somewhat from time to time, so as to reduce the necessary fluctuation of velocity to less objectionable limits.

3. That the traffic of the line would prove so thin (it was very doubtful) that the trains would for the most part be light and the necessity for either expedient not be great.

In this way it was possible to have one's cake and eat it too; to economize as much as was otherwise possible against the contingency of future poverty, and to lose nothing (but rather gain the interest on the cost of the fill) in case the future should prove prosperous; for at the worst the 1.15 line could certainly be operated as a virtual 1.25.

So pronounced an instance of the legitimate use of sags in grade-lines will rarely occur, but the same principle may be availed of often on a

* Velocity-head due to speed of 15 miles per hour (Table 118)	7.99 ft.
Add for depth of sag below virtual profile........................	25.00 "
Velocity-head in bottom of sag (giving speed of 30½ miles per hour),	32.99 ft

smaller scale, if only to introduce a little extra compensation in a long curve on a high fill, returning to the original grade-line by a slightly steeper grade beyond.

834. It will naturally follow from what has preceded that THE PROPER RATE OF COMPENSATION IS NOT A FIXED QUANTITY, but may under varying circumstances vary within somewhat wide limits. The more usual rates are from 0.03 to 0.05 per cent per degree of curvature, corresponding to 0.6 to 1.0 lbs. per ton per degree. If the precise amount of curve resistance were known, and if it were always the same, of course but one rate of compensation would be proper, but as its precise rate is not known, and as there is strong reason to believe (Appendix A) that in starting a train it may possibly amount to as much as 2.0 lbs. per ton, a compensation sufficient to equalize curve resistance in ordinary circumstances cannot be assumed to be certainly sufficient at points where speed may be expected to be very slow, as toward the top of long grades and occasionally at other points.

835. Under these circumstances, prudence would indicate that wherever there is NO PHYSICAL LIMIT to the possible reduction of grade on curves, it should be made ample, so that the curves should certainly offer no greater resistance than the adjacent tangents. At stations this rule would require a grade reduction of 0.1 per cent per degree.

On the other hand, when we are merely trying to equalize the tangent and curve resistance on a long ascent; and whatever is taken off the curves must be added on to the tangents and *vice versa*, no such practice is proper. A chain is only equal to the strength of its weakest link, and it avails little to know which is the weakest link if we cannot strengthen it. If we come as near to an exact equality as we can, in compensating for curvature, it is of no importance whether our compensation is a little too great or a little too small. In the one case trains will stall on the tangents and in the other on the curves—that is all. Our object is simply to guard against a CERTAINTY of stalling on either. Nothing more than this is important.

836. Hence it may well be that on a long and crooked ascent, where the curvature greatly exceeds the tangents, yet where there are one or two considerable tangents, prudence will require the assumption of a very low rate of compensation; for otherwise a very slight loss of elevation on each curve, multiplied by many curves, will prevent our attaining the desired summit at all without a considerable increase of the normal tangent grade. If we have guessed aright as to the real curve resistance, this may do no harm; but on the other hand, if we have guessed wrongly,

and exaggerated the probable curve resistance, we shall have unnecessarily increased our tangent grade. Hence, by assuming a low rate of curve resistance in such a case, we can hardly in any case lose anything appreciable, and may save a needless loss of grade. A compensation rate of 0.03 per degree of curvature may then be proper, below which the rate of compensation should never fall.

837. For the same reasons, it may well happen that at different points on the same line different rates of compensation may be proper. Where the loss of elevation by a high rate of compensation is a very serious matter, because of a great amount of curvature, it may be taken at a minimum. At other points, where there is less curvature to be compensated and a higher compensation can be had at little or no cost, it should there be used. The effect will be to make most of the maximum grade scattered over the division a little easier to handle trains on than the longest or worst grade. This may well result in handling a car or two more than would be deemed possible were the resistance as great at two or three points as it is at one.

It has been elsewhere said (see Table 124) that it is always worth while to keep a little below the maximum where possible, at moderate cost. This is only another application of the same principle, but, owing to the uncertainty which hangs about the question of curve resistance, it is a wiser way of attaining the same end than to reduce the nominal tangent grade, especially in the vicinity of stations.

838. To illustrate the importance of sometimes varying the rate of compensation to suit circumstances, assume a 1.5 per cent average grade, Fig. 185, nearly ten miles long (500 stations—taking a "mile" at 5000 ft. for convenience of computation), subdivided as follows in respect to amount of curvature:

Top. . . .	150 stations with about 50° per mile = (with ½ of the line tangent).	continuous	1° curve
Middle. . .	100 stations with about 300° per mile =	"	6° "
	100 " " " 400° " " = (with ½ of the line tangent).	"	8° "
Lower. . .	150 stations with about 80° per mile = (with ½ of the line tangent)	"	$1\frac{1}{2}$° "

Assume also a stopping-place near *B*, at the foot of the grade, so that no assistance from velocity can be counted on:

This is in no respect an unreasonably or improbably irregular distribution of curvature on such a line, nor an unusually large amount of curvature for a cheap line in rough country. In all there will be 150° + 600° + 800° + 225° = 1775° of curvature on the ascent.

ated as to make it essential to rise only some 230 feet, unless considerable extra expense were to be incurred, while at the same time the character of the line elsewhere was not such as to admit of a lower maximum tangent grade. Under these circumstances, which may frequently occur, it would be a great error not to reduce grade on curves by the full amount which the topographical conditions made possible without loss up to even 0.10 per cent per degree of curve, in the existing state of our knowledge, even if at other points we used less. In that case, if we have overestimated the probable or possible resistance on curves, it is not likely to do harm, because the large amount of curvature and small amount of tangents will enable any excess of resistance in the latter to be equalized by momentum, whereas if we have underestimated the curve resistance a similar effect is not possible, or at least not as fully possible, on account of the greater length of curves.

On the upper and lower sections, where tangents prevail and curves are the exception, the opposite principle prevails. If the curve compensation be too little it will be equalized easily enough by momentum on short and infrequent curves, so that the result will be the same in effect as if the balance were exact.

842. Under the circumstances of the example just considered, assuming the middle part of the grade to be fixed as just assumed, the proper course to pursue with the lower part of the grade would be to ease its rate a little, if circumstances permitted doing so at little or no expense; otherwise, to reduce its VIRTUAL rate by the simple expedient of removing the stopping point at the foot of the grade some distance from it, so as to ensure gaining something by momentum. A speed of 25 miles per hour at the foot of the grade reduced to 10 miles per hour at C will (Table 118) ensure a gain from surrendered energy of $22.20 - 3.55 = 18.65$ vertical feet (see Fig. 185), which will reduce the grade on the first 150 stations by $\frac{18.65}{150} = 0.124$ per cent, and so secure an equality with the virtual grade of the next section above, even with the lowest possible rate of curve resistance. The curve compensation on this lower section should in any case be small, whatever it may be on the middle section just above.

843. On the upper section DE, assuming the lower and middle section to have been fixed as above, an effort will naturally be made to lengthen the line a little at the upper end at the expense of a moderate amount of distance and curvature, so as to give a gradient DF instead of DE, Fig. 185; but if this be not possible, the disadvantage will not be very serious. Our case will be this: By virtue of an excess in rate of

sumed rates of compensation, have to be as shown in Table 186; and it will be seen that the middle point *c* of the entire grade comes at about the same elevation with either rate of compensation, but that there is a material difference in the height of the grade-line at the beginning and end of the middle sections *C* and *D*, or at the "quarter points" of the grade. While the through uncompensated grade-line falls as shown by the dotted line, the effect of introducing the curve compensation, by whatever rate, is to give a profile like the solid line, the point *C* being from 11½ to 38 feet higher than before, and the point *D* from 9 to 31 feet lower, according to the rate of compensation.

Table 186.

ILLUSTRATING THE EFFECT OF DIFFERENT RATES OF CURVE COMPENSATION TO MODIFY THE ELEVATION OF INTERMEDIATE POINTS ON LONG GRADE-LINES.

[Based on the data of par. 838 and Fig. 185.]

	1.5 Straight. No compensation.		1.6065 Tangent Grade. .03 compensation.		1.6775 Tangent Grade. .05 compensation.		1.855 Tangent Grade. .10 compensation.	
(Foot of Grade.)	Rise.	Elevation.	Rise.	Elevation.	Rise.	Elevation.	Rise.	Elevation.
B	....	0.	......	0.00	......	0.00	......	0.00
C	225	225.	236.48	236.48	244.12	244.12	263.25	263.25
c	150	375.	142.65	379.13	137.75	381.87	125.50	388.75
D	150	525.	136.65	515.78	127.75	509.62	105.50	494.24
E (summit).	225	750.	234.22	750.	240.38	750.	255.75	750.

Difference in Resulting Elevations at Various Points on the Grade, from the Straight Tangent Grade.

B (foot of grade)	*Constant*	——	——
C	11.48 ft. *higher*	19.12 ft. *higher*	38.25 ft. *higher.*
c	4.13 " "	6.87 " "	13.75 " "
D	9.22 " *lower*	15.38 " *lower*	30.76 " *lower.*
E (summit)	*Constant*	——	——

Topographical conditions will sometimes permit, but will more usually forbid assuming that we have such leeway in the necessary position of the grade, thus depriving us in a measure of the privilege of free choice.

841. Now suppose, on such a grade, that the middle 200 stations or about 4 miles, on which most of the curvature is bunched, was so situ-

ated as to make it essential to rise only some 230 feet, unless considerable extra expense were to be incurred, while at the same time the character of the line elsewhere was not such as to admit of a lower maximum tangent grade. Under these circumstances, which may frequently occur, it would be a great error not to reduce grade on curves by the full amount which the topographical conditions made possible without loss up to even 0.10 per cent per degree of curve, in the existing state of our knowledge, even if at other points we used less. In that case, if we have overestimated the probable or possible resistance on curves, it is not likely to do harm, because the large amount of curvature and small amount of tangents will enable any excess of resistance in the latter to be equalized by momentum, whereas if we have underestimated the curve resistance a similar effect is not possible, or at least not as fully possible, on account of the greater length of curves.

On the upper and lower sections, where tangents prevail and curves are the exception, the opposite principle prevails. If the curve compensation be too little it will be equalized easily enough by momentum on short and infrequent curves, so that the result will be the same in effect as if the balance were exact.

842. Under the circumstances of the example just considered, assuming the middle part of the grade to be fixed as just assumed, the proper course to pursue with the lower part of the grade would be to ease its rate a little, if circumstances permitted doing so at little or no expense; otherwise, to reduce its VIRTUAL rate by the simple expedient of removing the stopping point at the foot of the grade some distance from it, so as to ensure gaining something by momentum. A speed of 25 miles per hour at the foot of the grade reduced to 10 miles per hour at *C* will (Table 118) ensure a gain from surrendered energy of $22.20 - 3.55 = 18.65$ vertical feet (see Fig. 185), which will reduce the grade on the first 150 stations by $\frac{18.65}{150} = 0.124$ per cent, and so secure an equality with the virtual grade of the next section above, even with the lowest possible rate of curve resistance. The curve compensation on this lower section should in any case be small, whatever it may be on the middle section just above.

843. On the upper section *DE*, assuming the lower and middle section to have been fixed as above, an effort will naturally be made to lengthen the line a little at the upper end at the expense of a moderate amount of distance and curvature, so as to give a gradient *DF* instead of *DE*, Fig. 185; but if this be not possible, the disadvantage will not be very serious. Our case will be this: By virtue of an excess in rate of

curve compensation we have the broken virtual gradient *ACDE* instead of the straight grade *BE*, which is of course preferable. The disadvantage at the lower end, which would naturally be the most serious (par. 828), since it carries our virtual gradient above the grade-line *BE*, which we desire, we have neutralized by momentum.* The disadvantage at the upper end, since it merely carries our profile a little below the grade-line, will in great measure, if not entirely, neutralize itself by momentum.

In this way we have done the best which can be done to avail ourselves of every chance in our favor, whereas by assuming any hard-and-fast rule whatever, and then following it blindly (as we might be justified in doing if we knew it was correct), we are certain to lose something, and may lose a good deal.

844. Our practical conclusions as to rate of curve compensation, therefore, may be summarized as follows:

1. With short grades or under favoring topographical conditions compensate as liberally as possible up to a maximum at special points of 0.10 per cent per degree.

2. Where speed may sometimes be very low, and hence invariably on or very near to known stopping-places, this maximum rate appears, with our present knowledge, none too much. In general, however, 0.05 per cent per degree (= 1 lb. per ton) is an ample equivalent for curve resistance, and *for fast trains alone* probably 0.02 to 0.03 per cent (= 0.4 to 0.6 lb. per ton) is sufficient to balance the resistance.

3. On sections where curves largely predominate over tangents it is particularly desirable to have ample compensation, and if excessive it will do least harm. On the contrary,

4. On sections where the amount of curvature is small it is less important to have full compensation, and if excessive it will do most harm.

5. When the rate of compensation can only be increased at the CERTAIN cost of a corresponding increase in the rate of tangent grades (making very sure that it is certain, and not an over-hasty

* The word "momentum" here and elsewhere is used in a somewhat unscientific way, to correspond with the popular use of the word. The scientist will not be confused thereby, while the average reader is assisted.

conclusion from inexperience or lack of care), no larger rate than we feel practically certain will be required to balance the curve resistance (0.03 to 0.04) should be chosen.

Otherwise, we are committing the folly of making a certain addition to the grade in one place, to avoid one in another place which is merely problematical.

6. On any minor gradients where the curvature is not sufficient to bring the virtual profile up to the maximum it is not important to compensate for curvature at all, although it is generally as well to do so, especially at points where to do so will slightly reduce the cost of construction, as is very apt to be the case on long curves.

When not compensated, the curvature merely has an equivalent effect to a slight undulation of gradient (Class A of rise and fall, par. 438) which produces no shock to the train and so is not a measurable disadvantage.

7. It is not in the least essential or important to precisely adapt the compensation to the exact length of each curve. The reduced rate may as well as not begin and end at the nearest even station, and may be made a little less on one curve and a little more on one immediately above if a horizontal slice of a foot or more may thereby be taken off a high fill on the tangent connecting them, *but never so as to cause the grade to rise* ABOVE *the uniform grade-line.*

8. Curves immediately below a known stopping-place for all trains need not and should not be compensated at all.

9. The rate of compensation should be uniform per degree for all degrees of curvature, or in no case made greater for the sharper curves. It may even be made less for curves of over 10° [par. 335 (9)]. If the rate be reduced one half for the excess over 10°, making the compensation for a 16° curve thirteen times that for a 1° curve, it will certainly lead to no bad results, although a rather rough rule.

This is directly contrary to the usual practice, which is to increase the rate of compensation with the sharpness of the curve, if anything; but this practice rests upon the assumption which we have seen to be the direct contrary of the truth (par. 321 *et al.*), that the curve resistance increases with the degree of the

curve. The results of experience on the New York elevated lines and numerous others with very sharp curves, both of standard and narrow gauge, is enough to disprove this, confirmed as it is very directly by the indications of theory.

10. Since we have seen in Chap. VIII. (par. 330–335) that there is no reason to believe that curve resistance increases per ton with the length of the train, or even (appreciably) with the type of engine (par. 285 *et seq.*) there is no reason for varying the compensation because of the grades or length of train, except for this—that it is usually easier to spare the elevation for a liberal rate of compensation with low grades than with high ones. It is therefore proper to do so.

CHAPTER XIX.

THE LIMIT OF MAXIMUM CURVATURE.

845. ALTHOUGH badly adjusted grades have a more serious effect on operating expenses, there is no detail connected with location which has so great an effect on the cost of construction as that which we are about to consider—nor any in which the tendency is so notable to go to one extreme or the other, without any very definite or defensible reasons. It is evident that, while circumstances will often justify and require the use of very sharp curvature or of very easy curvature, they will in no case either justify or require that conclusions should be jumped at in some such manner as that sketched in par. 245.

846. Moreover, it may be again repeated, and cannot be too fully recognized and clearly borne in mind, that both the amount and radius of curvature, like the amount and rate of grades, is even more dependent upon study, care, and skill than on topography. There exists, too, a most dangerous tendency to use more and sharper curvature than is at all necessary in country of some difficulty, and less and easier curvature than is at all expedient in country of no difficulty, or in country whose only difficulty comes from trying to hold close to an air-line (Chap. XX.). Errors of this kind, resulting merely from lack of care or skill, are especially apt to lead to the use of absurdly sharp curvature if one has imbibed the notion that easy radii are unimportant.

847. Recognizing these dangers, we proceed to analyze, as nearly as may be, the causes which fix the advisable limit of maximum curvature and the cost of exceeding it. We have seen (par. 343) that these causes may all be separated under the two following heads, sharply defined from each other:

First. THE INHERENTLY GREATER COSTLINESS, ***not of curvature measured by degrees, but of*** SHARP CURVATURE INSTEAD OF EASY CURVATURE *for approximately the same number of degrees.* In other words, the greater wear and tear of track and rolling-stock, consumption of fuel, danger of accident, loss by decreased speed, etc., which results from using 100 feet of 10° curvature instead of 1000 feet of 1° curvature for deflecting the line through a central angle of 10°, or from using 900 feet of 10°, and 550 feet of tangent at each end, for deflecting through an angle of 90°, as in

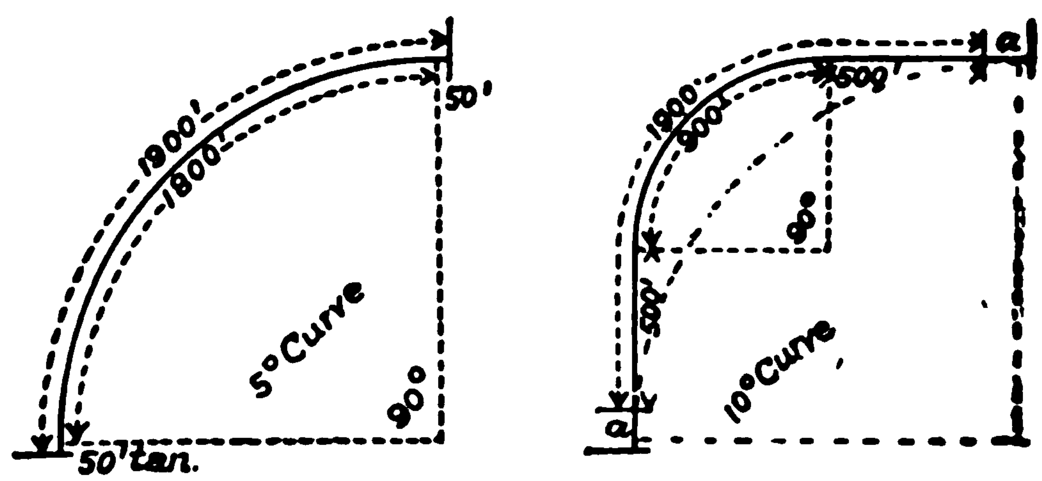


FIG. 186. FIG. 187.

[There is a certain loss of distance, *aa*, in using the sharper instead of easier curve, which is not referred to in the text. See par. 859.]

Fig. 187, instead of using 1800 feet of 5° curve and only 50 feet of tangent, as in Fig. 186.

Secondly. THE LIMITING EFFECT OF SHARP CURVATURE on the weight and length of trains, provided it be sharp enough to have such effect. Some is, and some is not.

848. In other words, we are here met, upon the threshold of the subject, with a distinction precisely analogous to that which we have already found (par. 361) to exist in the case of gradients. ALL grades, without distinction and wherever situated, entail a certain additional expense per train passing over them; and in addition to this the highest rate of grade entails a certain and much greater expense which does not appear at all in the expenses per train-mile (except as it may tend to decrease them by shortening trains), but solely in an increase in the number of trains. In like manner, ALL curves, without distinction, entail a certain additional expense per train passing over them for every

degree of the curve, and this cost, it may be,—or may not be,—increases rapidly with the sharpness of the curve; but in addition to this, the sharpest curve (or curves) on the line, *if it be sharp enough*, will have the further effect of limiting the weight and length of trains. In fact, if made sharp enough, it will so severely limit the weight of trains as to make it impossible to run any trains at all.

At a certain definite radius, therefore, the expense and loss arising from short radii take a sudden jump. The inherent cost per train-mile per degree of *sharp instead of easy* curvature continues on as before, and, in addition thereto, there is the large additional expense caused by the limiting effect of any shorter radius upon the weight of trains.

849. It is plain that the point at which this sudden jump will or may occur is intimately connected with and depends upon the rate of the maximum grade, because the higher the grade the greater the resistance on a tangent, and hence the sharper the curve which may be used (i.e., which it is possible to use) on levels or minor gradients without any limiting effect on trains. Hence the shorter the trains which can be hauled independent of the sharpest curve, the shorter the radius which may be freely used on levels or minor gradients without affecting the number of trains required for a given business.

850. Now, just as in the case of gradients, this distinction between these diverse sources of expense is one which must be carefully kept in mind if any correct and intelligent decision as to the limit of maximum curvature is to be reached.

In the first place, it needs no great effort of mind to perceive that the first item mentioned above, the inherent costliness of sharp curvature,—that portion which is visible in increased wear and tear and expenses per train-mile,—affords no ground for the fixing of any arbitrary and inflexible standard or limit, nor should it be considered or allowed to have ANY WEIGHT WHATEVER in ascertaining at what radius to fix that limit. For, making for a moment the exaggerated estimate that the cost of curvature per degree increases as the square of the degree of

the curve, it may easily be, and often is the case at certain points, that the cost of construction will vary as the cube of the radius, and hence a sudden sharp ravine or rocky spur might justify and require a 12° or 15° curve for this account alone, although 3° or 4° curves were the maximum on all the rest of the line. But what we then require to determine is: Will any such curve have the further effect of limiting the weight of trains over the whole line, or injuriously restricting speed? For in that case, plainly, a large additional expenditure will be justifiable to increase its radius.

851. This latter expenditure does not vary with the number of curves, as does the wear and tear, but is a certain fixed amount, which can alone be used to take out such curves, however many or few they may be, and must be distributed to one curve or to fifty, according to their number. This fact alone is sufficient to show the essential dissimilarity between it and the sum which represents the direct or INHERENT disadvantage of using short instead of long radii. As the latter is always so much per sharp curve, or per degree of sharp curvature, it always has its effect—much or little, as the case may be—on the justifiable expense to increase the radius of each particular curve, for it is to be added in each case to the proportion for that curve of the estimated value of avoiding any limiting effect from its radius; but it does not form an element in fixing the point at which limiting effect begins, and hence should be allowed no weight whatever in ascertaining that limit.

All this seems clear enough when the attention is specially directed to it, but, as with many other problems which advance from simple premises, it requires a constant effort of the mind to keep it always in view. Hence, although it has no real or necessary connection with our present subject, we may first briefly consider

THE INHERENT COSTLINESS OF SHARP CURVATURE.

852. For the consideration of this question all actual or possible limiting effect from curvature on the length or speed or easy riding of trains, or the use of any desired type of locomotive, must be disregarded. Such

injurious effect as the sharpest curves may have on these details, if any, is another matter. The question is simply—as between the two methods shown in Figs. 186, 187—of turning an angle of 90° within a distance of 1900 feet of track : Which adds the most to the operating expenses per train due to that 1900 feet—the method of Fig. 186, showing 1800 feet of 5° curve and 50 feet of tangent at each end, or that of Fig. 187, with 900 feet of 10° curve and 500 feet of tangent at each end?

853. Rigorously excluding all thought of possible limiting effect from the mind, it is very difficult to see reasons why the inherent cost of curvature, per train-mile per degree, should be in the least increased by using short instead of long radii, i.e., by using 100 ft. of 10° curve instead of 1000 ft. of 1° curve, to cover the same central angle. The wear and cost of rails appear from superficial investigations (the writer's among others: see par. 317) to indicate that rail wear increases faster than—or even (as the writer once suggested) as the square of—the degree of curvature; but this is a purely deceptive appearance, due to the fact that the *rate* of wear increases as the rails become worn to "fit the flange" (par. 338), and thus expose a greater area to rubbing friction. It is plain that at any given date in a large lot of rails laid at the same time those on the sharper curves will have fulfilled a greater proportion of their total life, and hence will have begun earlier to wear more rapidly. From a more correct comparison of all the data it appears rather as if both curve resistance and rail wear (and hence fuel consumption) increased more slowly instead of faster than the degree of the curve (par. 311). If so, the total RAIL WEAR caused by 10° of central angle will be less, rather than more, on a 10° curve than on a 1° curve. While this cannot as yet be positively asserted, it may be regarded as certain that the balance is at least even.

854. It may with far more certainty be claimed that the cost of MAINTENANCE OF ROAD-BED AND TRACK is considerably decreased, per degree of central angle, by the use of short radii, because a good portion of it is nearly constant per 100 feet of curve, regardless of radius, such as the extra cost of lining, maintaining uniform and proper elevation, and the shorter life of ties, in order that they may be capable of sustaining the lateral reaction of the rails, which latter is theoretically (although probably not quite practically) the same on all curves (par. 311).

It would be a most liberal estimate to assume that the additional cost per station for maintaining road-bed and track due to curvature increases as the square root of the degree of curvature, making it 3.16 times as much per 100 ft. of line on a 10° curve as on a 1° curve, or making

the additional cost due to $A°$ of central angle compare as 1.0 on a 1° curve to 3.16 on a 10° curve. This entire item is a small one, but so far as it goes it is distinctly favorable to the use of sharp instead of easy curvature.

855. Figs. 186, 187 are literal copies of diagrams which the writer

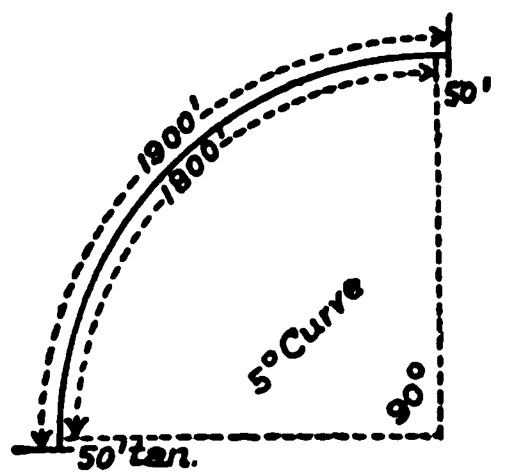


FIG. 186.

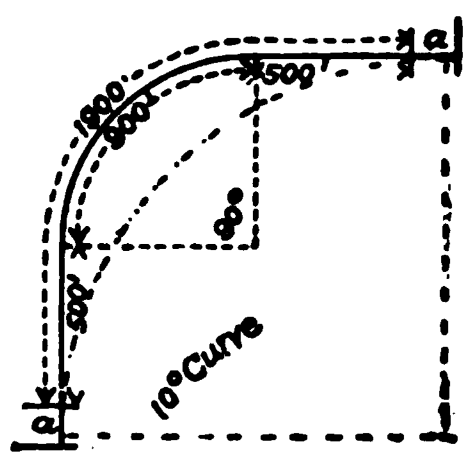


FIG. 187.

submitted to two or three of the most thoughtful practical road-masters of his acquaintance for an opinion as to probable comparative maintenance expenses. The reply of one of them was as follows:

"Assuming a tie to last 8 years on tangent it will last about 6 years on a 10° curve, so as to keep gauge safe, and we will say 7 years on the 5° curve. Then—

For 10° *line*—Cost of ties for eight years on 1000-ft. tangent,		
500 ties at 50 cts., ...	$250 00	
450 ties on 900 ft. of 10° curve at 50 cts. = $225 for 6 years,		
= for 8 years, ...	300 00	—$550 00
For 5° *line*—Cost of ties for 8 years on 100-ft. tangent, 50		
ties at 50 cts., ...	25 00	
900 ties for 1800 ft. of 5° curve, at 50 cts. = $450 for 7 years		
= for 8 years, ...	514 30	—$539 30

"Therefore there is a saving of $10.70 at the end of 8 years in favor of the 5° line, and we may conclude that the maintenance of line and surface will bear the same proportion as ties.

"According to this figuring there is a saving of about 2 per cent in maintenance in taking the 5° line. This is small, and in looking at the two lines in all their bearings I believe the 10° line is the preferable one for maintenance, as on it we get more tangent than curve, while the 5° for the same distance is nearly all curve and very little tangent."

The fallacy in the first part of this estimate, which was perceived but not located, lies in assuming that a 5° curve will only diminish the life of a tie half as much as a 10° curve: which is hardly so, the flange pressure being the same on both. Moreover, the extra work of lining and

surfacing is, still more nearly, so much per lineal foot of curve, regardless of the radius.

856. The wear and tear of WHEELS AND RUNNING GEAR of rolling-stock will naturally follow the same general law as the rail wear, so that it may be considered to vary directly as the degree of curvature, remaining constant per degree of central angle.

857. Moreover, the total cost of repairs of rolling-stock and track, for those items which are at all liable to be affected by the wear and tear and loss of power on curves, is very small, as thus:

		Per cent of total expenses.
Engines, 19 per cent only of the total cost of repairs appears to vary with curvature *and* grades (Table 85); 19 per cent of 5.6 per cent (Table 80), ...	=	1.07
Cars (Table 86), 23 per cent appears to vary as above; 23 per cent of 10.0 per cent (Table 80), ...	=	2.30
Rails, say 50 per cent of 2.0 per cent, ...	=	1.00
Fuel, say 10 per cent of 7.6 per cent, ...	=	0.76
A total per cent of only		5.13

Thus only about 5 per cent of the total operating expenses is likely to be affected at all by curvature, and a good part of that only slightly, and a good part of what remains by sharp and easy curvature of equal amount nearly equally.

858. It is also to be remembered that sharp curves LENGTHEN SHORT TANGENTS, as is clearly brought out by Figs. 186, 187—an advantage which facilitates what would otherwise be impossible, the use of easy transition curves (see Index), and hence may be made to greatly decrease the unavoidable shock in entering and leaving curves.

859. The effect of a change of radius on the TOTAL LENGTH OF THE LINE, although apparently pertinent, has no real bearing on this question. The use of sharp curvature always increases the length of the line between the same tangents by the amount *aa*, Fig. 187, and has besides a marked further tendency both to increase the length of the line and to increase the degrees of central angle, because of the differences of location which naturally result. But the disadvantage of this extra length and curvature is a matter for separate estimation, because it is not an essential and unavoidable feature of a mere change of radius, and hence does not directly, although it commonly will indirectly, affect the decision in favor of using easy curvature. In fact, although it rarely occurs in practice, it is not in the nature of things impossible, that the use of a

shorter radius should result in a decrease of both distance and degrees of central angle. On a small scale it very frequently does so, in the manner outlined in Fig. 188.

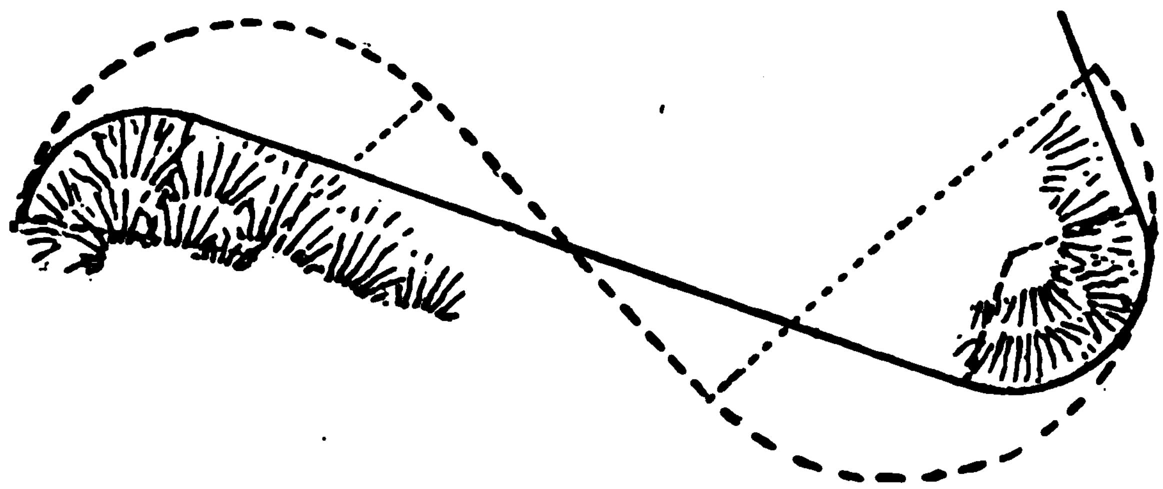


FIG. 188.

860. On the other hand, it may well happen that the adoption of a location adapted to short radii would double the amount of curvature and that the estimated cost of this would be more than the estimated saving on construction. In that case the short radii would not be used, but they would be abandoned, not because of the sharpness of the curvature, but because there was so much of it.

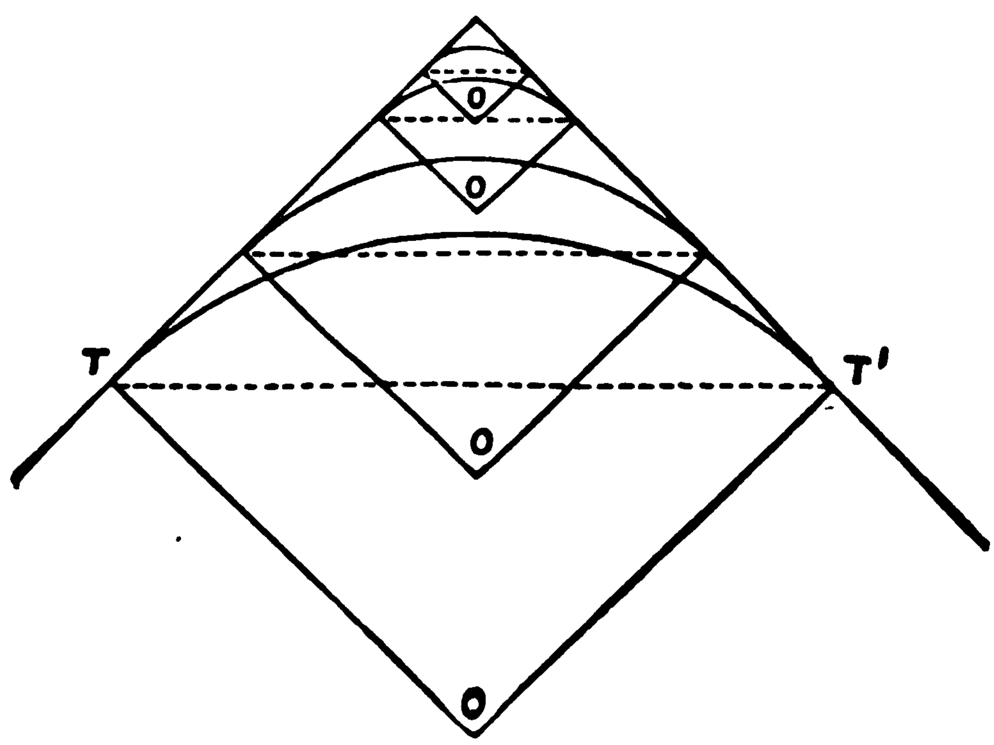


FIG. 189.

861. The loss or gain in distance by connecting any two given tangents with one curve instead of another, Fig. 189, may be very simply determined as follows:

TO DETERMINE THE DIFFERENCE IN LENGTH OF LINE *via* ANY TWO CURVES OF DIFFERENT RADII, CONNECTING THE SAME TANGENTS:

Let l = length of longer curve, of $D°$, with tangents T;
" l' = " " shorter " " $D'°$, " " T'.

Then geometrically $\frac{l}{l'} = \frac{D}{D'} = \frac{T'}{T'}$, if we assume, as for all practical purposes we may,—if curves of over 8° or 10° are run in with 50-foot chords,—that the degree of curvature is directly as the radius.

$$\text{Then } l' = \frac{D}{D'}\, l \text{ and } T' = \frac{D}{D'} T, \qquad T - T' = \left(1 - \frac{D}{D'}\right) T.$$

Letting $L =$ the length *via* any one of the sharper curves shown in Fig. 189, from tangent-point to tangent-point of any curve of longer radius (from T to T) we have

$$L = l' + 2(T - T') = \frac{D}{D'} l + 2T\left(1 - \frac{D}{D'}\right),$$

$$L - l = 2T\left(1 - \frac{D}{D'}\right) - \left(1 - \frac{D}{D'}\right) l,$$

$$= (2T - l)\frac{D' - D}{D'}.$$

But the value of $2T - l$ for a $D°$ curve is to its value for a 1° curve as $\frac{1}{D}$. Consequently, tabulating $(2T - l)$ for a 1° curve, we have as *the difference in the length of the line via any two curves of D and D' degrees, connecting the same tangents :*

$$= \text{tabular number} \times \frac{1}{D} \times \frac{D' - D}{D'}$$

$$= \text{tabular number} \times \frac{D' - D}{D'D}$$

$$= \text{tabular number} \times \frac{\textit{difference}}{\textit{product}} \textit{ of the two degrees of curvature.}$$

862. Table 187 gives such a tabulation for angles differing by 1° up to 130°. The "tabular number" is simply the difference between the length of a 1° curve of any given central angle and the lengths of its tangents. It is therefore given for any angle whatever by the formula

$$T = \tan \tfrac{1}{2} I \times 5730 \times 2 - 100 I;$$

in which $T =$ tabular number for Table 187,
$I =$ intersection angle in degrees.

The problem is rarely one of practical importance, since two curves of considerable difference in radius rarely connect the same tangents, but is sometimes convenient for determining the effect of minute changes. For the two curves shown in Figs. 186, 187, we have—

Tab. no. for 90° (Table 187) $= 2459.3 \times \frac{1}{10}\left(\frac{10 - 5}{10 \times 5}\right) = 246$ feet loss of distance by the 10° curve.

TABLE 187.

DIFFERENCE IN LENGTH OF LINE *viâ* ANY TWO CURVES OF DIFFERENT RADII, CONNECTING THE SAME TANGENTS.

[To determine the required difference, multiply the tabular number below, corresponding to the given central angle by the $\frac{difference}{product}$ of the two degrees of curvature.]

	0	1	2	3	4	5	6	7	8	9
0°	0.00	0.00	0.02	0.08	0.16	0.32	0.56	0.88	1.32	1.86
10°	2.56	3.40	4.42	5.62	7.02	8.64	10.50	12.60	14.98	17.62
20°	20.6	23.8	27.4	31.4	35.8	40.4	45.6	51.2	57.2	63.6
30°	70.6	78.0	86.0	94.2	103.4	113.2	123.4	134.2	145.8	158.0
40°	170.8	184.4	198.8	214.0	229.8	246.6	264.2	282.6	302.0	322.4
50°	343.6	365.8	389.0	413.4	438.8	465.4	493.0	521.8	552.0	583.4
60°	616.0	650.0	685.4	722.2	760.6	800.4	841.8	884.8	929.4	975.8
70°	1023.8	1073.8	1125.6	1179.4	1235.2	1293.0	1353.0	1415.2	1479.6	1546.4
80°	1615.4	1687.2	1761.4	1838.4	1918.0	2006.0	2086.0	2174.4	2266.2	2361.0
90°	2459.4	2561.0	2666.4	2775.6	2888.6	3005.6	3126.8	3252.4	3382.4	3517.2
100°	3656.4	3801.2	3951.0	4106.4	4267.2	4434.0	4607.0	4786.4	4972.4	5165.4
110°	5365.6	5573.4	5789.2	6013.2	6245.8	6487.6	6738.8	6999.8	7271.4	7554.0
120°	7848.0									

This table is NOT correct to the nearest tenth, but only to the nearest even two-tenths. As a certain small fraction only of the tabular number is to be taken, the error was not deemed of enough moment to require recomputation. The table gives merely the difference between the length of the two tangents to a 1° curve and the length of its arc, for any given central angle.

863. Precisely this same method of analysis will enable us to determine at once the difference between the radius, long chord, middle ordinate, tangent, or any other function of any two similar curves if we know the value of the same function for a similar 1° curve. Thus the difference between the radii of a 5° and 10° curve is

$$5730 \times \frac{10-5}{10 \times 5} = 573.0 \text{ feet;}$$

and between a 7° and 8°, $$5730 \times \frac{8-7}{8 \times 7} = \frac{5730}{56} = 102.3 \text{ feet.}$$

864. From all the considerations which have been suggested together we may perhaps assume that the inherent cost of curvature per train-mile is independent of the radius, or at least does not increase appreciably with the sharpness of the curve, and this

view simplifies a decision as to the limit of radius. But whether this view be entirely correct or not is a matter of perfect indifference for deciding the problem immediately before us, as it is hoped has been made perfectly clear.

Dismissing, therefore, from our minds this confusing and irrelevant question, we will now confine our attention exclusively to the LIMITING EFFECT of curvature as the only cause which justifies the fixing of any arbitrary limit whatever to the sharpness of curves.

THE LIMITING EFFECT OF CURVATURE.

865. Curvature may have a limiting effect in three ways:

1. It may forbid the use of certain types or weights of engines, or so impede it as to make it practically inexpedient. The extent to which this cause does or may operate has been already considered (par. 285 *et seq.*) and found to be small.

2. It may impede the running of trains at high speeds by the necessity of frequently checking speed or maintaining a low rate of speed for considerable distances when the intervals between the sharper curves are small.

3. It may compel the hauling of shorter trains by its addition to curve resistance.

The second cause has been already considered from the mechanical side (in par. 268 *et seq.*) and found to appreciably affect passenger trains alone.

866. As a business question, the effect which we there saw sharp curves to have on the safe speed shows their use to be on many roads of heavy passenger traffic a consideration of extreme importance, justifying and requiring an extremely low limit of curvature. Nevertheless, under average conditions, the same facts show it to be one of minor importance.

867. It depends chiefly on a road of any given character on the amount and disposition of the sharp curvature. Thus on the elevated railways of New York, with, perhaps, the heaviest passenger traffic in the world, a few excessively sharp curves are used, such as those shown in Figs. 189, 190, 191. These are not found

FIG. 190.—REVERSED CURVES OF 110 FEET RADIUS ON MANHATTAN ELEVATED RAILWAY. THIRD AVE. LINE.

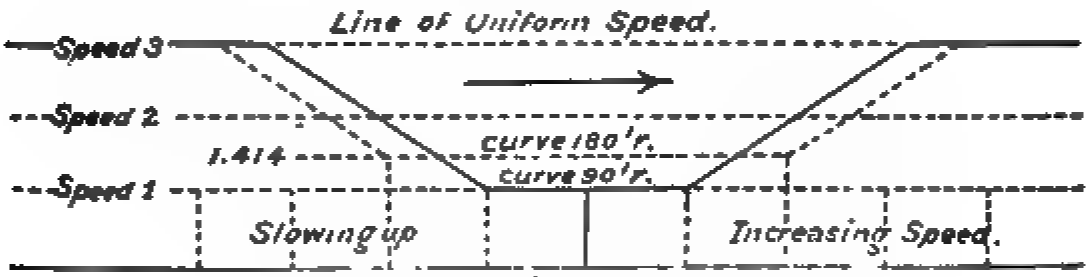


FIG. 191.—ILLUSTRATING THE EFFECT OF LONGER RADIUS ON COMPARATIVE SPEED.

to be a measurable disadvantage as respects limiting speed (for if they were, a few thousand dollars would take them out), because, although every moment of lost time is of great importance, the speed between the frequent stops is slow (not over 30 miles per hour) and the motive-power between stations (because of the frequency of stops) abundant. Therefore the speed is checked to a safe limit almost instantaneously on approaching the curve, and resumed again on passing it almost as quickly, and the total loss per curve does not exceed 20 to 30 seconds for each curve; only a small of part which $\left(\frac{1}{\sqrt{2}}\right.$ or 39. 3 per cent, on curve and $\frac{1}{2}$ or 50 per cent in approaching and leaving the curve, as a brief analysis, which the student should make, will show$\left.\right)$ could be saved by doubling the radius of curvature. Fig. 192 and Table 107, page 273, will indicate the method of determining this.

868. If, however, there were many of these curves, the loss of time would not only increase *pari passu*, but, by frittering away the time and nervous energy of the engineman, obstructing his view ahead, and similar indirect causes, cause a still further decrease in the practicable speed, and likewise decrease the admissible frequency of trains, thus causing an unwarranted loss, if any ordinary expenditure would avoid it. As the line now stands, an avoidance of all curves on the line would have a considerable money value, but to simply double the radius would be worth little or nothing—as is sufficiently evidenced by Figs. 189–190. The management is not unintelligent nor unduly parsimonious, but it is not thought of, simply because it would not pay.

869. So on the various railway lines connecting Boston, New York, Philadelphia, Baltimore, and Washington. The value of avoiding any considerable amount of curvature, and especially curvature sharper than 3° or 4°, is to be measured only by a vast sum, under the growing business advantage of very fast trains. Its existence in large amounts would make quick time impossible; but the same is not at all true of a small amount of curvature at some one point, even of very short radius, for reducing

speed *for one mile only* from 60 to 30 miles per hour means only the loss of $1\frac{1}{2}$ to 2 minutes time (Table 183). The justifiable expenditure to avoid it would certainly be far less than one tenth of what would be justifiable on the same line to avoid ten times as much curvature and delay, both because (1) more than ten times as much time would be lost thereby, and because (2), even if not, the loss would be more than ten times as injurious. Two minutes more time between New York and Philadelphia might not place a competing line under measurable disadvantage. Twenty minutes would not simply decrease, but destroy its chance for competition on equal terms.

870. When we come to long trips, of 500 to 1000 miles, we have already (par. 240) seen that any probable loss of time which is remediable by any expenditure within bounds for easing curvature is not likely to have any effect whatever, measurable in dollars and cents, upon competitive equality. The most trifling differences in neatness of stations and equipment, courtesy of employees, character of "lunch counters," etc., would be far more important for that purpose, as well as far more cheaply obtained.

871. The true principle in regard to this matter would therefore seem to be: TO ESTIMATE THE TOTAL LOSS OF TIME which is likely to result, on a given line, from the location naturally resulting from one radius of curvature instead of another, and the probable money value of so much competitive business as is likely to be lost on account of this loss of time. While this is an exceedingly delicate and difficult matter to estimate even approximately, and an impossible one to determine with exactness, yet (par. 21) "what we can do is to fix a maximum and minimum limit, somewhere within which lies the truth and anywhere outside of which lies a certainty of error. Due judgment and caution require that we should do so."

872. As a general rule, the limiting line between the traffic to which every minute is and is not important lies at the point where it ceases to be possible to make a round trip in a day, with some time to spare at destination. For distances under 100 or 150 miles this is possible, as for instance between New York and

iladelphia, and time is valued greatly. For longer distances, from New York to Boston, this is not possible, and fast trains re not run, nor are they likely to be until over 50 miles per hour an be made, when there will be demand for several daily. Between New York and Chicago, until it finally appeared possible to shorten up the time to 24 hours, quicker time than 36 hours was not important, and was not made. To St. Louis, which is only 200 to 250 miles further from New York than Chicago, or some 20 per cent, the time is still eight or ten hours longer, for the same reason.

The effect of sharp curvature on safety and the comfort of travellers is considered in Chap. VIII., pars. 247 and 279.

873. We will now analyze the extent to which the third and chief cause for limiting effect from curvature operates—that it may compel the hauling of shorter trains by its addition to the train resistance:

We have on the tangent maximum grade, whatever it may be, two resistances to overcome:

1. The ordinary rolling-friction.
2. The resistance of gravity—a known and constant quantity.

In the case of curvature on a level we have also two resistances:

1. The ordinary rolling-friction, as before.
2. All additional resistance which may or can arise from the curve.

In either case, it is evident that the resistance from the rolling-friction proper, being the same in any case, whatever its amount may be, may be entirely neglected. In any case, also, it is obvious that the grade on any curve may be reduced to a level, if desired, so as to eliminate all grade resistance.

874. The normal rolling-friction being eliminated, what we require, in order to determine the proper limit of maximum curvature *so far as length of train is concerned, i.e.*, the point at which a LIMITING EFFECT begins, or should begin on a properly laid out line, is simply *the curve on which, in all cases and under the most unfavorable circumstances, the same engine can haul the same train on a level as it can haul on a tangent up the maximum grade.*

It is not sufficient to determine merely the curve on which there will *probably* be no greater resistance on a level than on the tangent maximum grade, nor the curve on which, under average or favorable conditions, there will be no limiting effect. When there is even a possibility that under any circumstances whatever, exceptional or unexceptional,

the resistances on a level maximum curve may exceed the known and invariable effect of gravity on the actual tangent maximum grade, that curve is in a sense a limiting curve, because there is a certain disadvantage in even the possibility that curvature may at times limit the trains in advance of gradients, and hence a certain money value in avoiding it.

875. Viewed from this standpoint, with our existing experimental knowledge of curve resistance, all that can safely be assumed is that an allowance of 2 lbs. per ton per degree of curvature is none too great to cover the highest *possible* curve resistance at very low speeds, with well-worn rails and long trains of empty cars, especially on easy curves. So high a curve resistance is, we may be very certain, rarely reached in practice, but that it is sometimes reached is at least possible.

On the other hand, the very lowest limit for the resistance on ordinary railway curvature, under the most favorable circumstances, at high speeds and with new rails, is probably about (somewhat less than) ½ lb. per degree of curvature, falling on the very sharpest curves, such as on the elevated railways of New York, to something less than ⅛ lb. per ton per degree; but the latter curves are out of the range of ordinary experience.

876. The assumed 2 lbs. per ton of train resistance is equivalent to 0.1 per cent of grade, and 0.5 lb. to 0.025 per cent of grade. Multiplying the former, therefore, by the degree of any curve, gives a rate of maximum grade which will certainly oppose more resistance to all trains under all circumstances than the given curve will on a level, while multiplying the latter by the degree of curve, in the same way, will give a rate of maximum grade which will certainly NOT oppose more resistance to any train under any circumstances than will the curve, and hence the latter will be, in the fullest sense, a "limiting" curve.

In between these limits sometimes the curve and sometimes the grade may offer the maximum resistance.

877. From the above simple data we may construct the following Table 188, showing the proper limits of practice in respect to maximum curvature:

Table 188 assumes that the most which can possibly be done to eliminate curve resistance is to reduce the grade to a level, which is the case with an evenly balanced traffic and with long stretches of level or undulating gradients having a great deal of curvature. It is evident, however, that under the three following conditions, at least, this is not the case, and hence that the table will not then apply:

TABLE 188.

ιUM AND MINIMUM LIMITS FOR THE DEGREES OF LIMITING CURVATURE ON VARIOUS GRADES.

:ing the degrees of the curves which certainly will and certainly will not cause a :r resistance on a level than a given tangent rate of maximum grade. Subject to the ιtions of pars. 878 *et seq.*]

TANGENT MAXIMUM GRADE.		DEGREE OF MAXIMUM CURVE ON A LEVEL	
Per Cent.	Feet Per Mile.	which will certainly have no limiting effect on any train under any circumstances.	which certainly will have a limiting effect on all trains under all circumstances.
0.1	5.28	1°	4°
0.2	10.56	2°	8°
0.3	15.84	3°	12°
0.4	21.12	4°	16°
0.5	26.40	5°	20°
0.6	31.68	6°	24°
0.7	36.96	7°	...
0.8	42.24	8°	...
0.9	47.52	9°	...
1.0	52.80	10°	...
etc.	etc.	etc.	

878. 1. On a long maximum grade, of any considerable rate, we can, if necessary, not only reduce it to a level, but break the grade to a descent, as at BB', Fig. 192, and in this way completely eliminate the limiting effect of the curve resistance of any curve, however sharp; for we have to consider trains in one direction only.

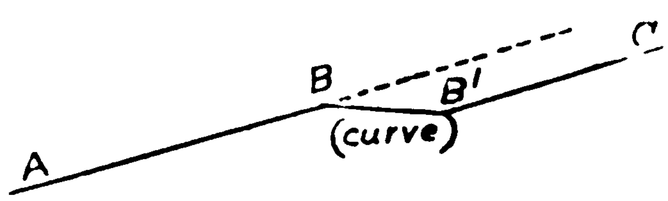


FIG. 192.

To descending trains the break of grade can (ordinarily) do no harm. On such a grade, therefore, there is no reason why any curve whatever should not be used, so far as the limiting effect of its resistance is concerned, and the other two causes alone (par. 865) justify fixing a limit of radius.

2. When the grade is level or slightly undulating for a considerable distance, and the percentage of curvature is not too great, some little assistance at least from momentum may be relied on, to eliminate a portion of the resistance of very sharp curves.

3. When the burden of traffic is heavily in one direction, as in mineral traffic, even with nearly level grades and with no assistance from momentum, quite sharp curves can be used wherever the necessary com-

pensation to equalize the curve resistance for trains *moving in one direction* can be made, because the loaded trains return light with a surplus of motive-power.

879. Summarizing our conclusions as to limit of maximum curvature, we have found:

1. That there is rarely (although there is sometimes) real difficulty in using engines of any desired power, of types approximate for efficient service, on any probable alignment, and (par. 285) that on curves below 10° or 12° there is no difficulty whatever.

2. That those railways are the exception (although they do exist) on which any probable loss of time from the necessity of slowing up at sharp curves will be a matter of much financial importance, and that the gain in this respect by any modification of curvature ordinarily possible is much less than is supposed.

3. That all danger of limiting effect upon the weight of trains from sharp curvature, within the limits specified in Table 188, can ordinarily be avoided, and that these limits afford sufficient range for using those curves which best fit the ground under all ordinary topographical conditions.

4. That the difference in danger of accident which is liable to result from any modifications of curvature ordinarily possible is too small for estimation, as an element justifying additional expenditure.

5. That the effect of any difference of radius on the expenses due to wear and tear and consumption of fuel per train-mile, the degrees of central angle remaining the same, is probably either *nil* or in favor of sharp radii; but that whether this be so or not (par. 252) is a question which should be allowed no weight whatever in fixing on a limit of radius.

6. That the effect of shorter radii, if they have any, to lengthen the line or increase the degrees of central angle, or both, through the different location which naturally results, is likewise a matter which does not directly affect the question, although it often may indirectly.

880. We may likewise close, as we began, with another very important conclusion:

7. That the natural tendency of inexperienced engineers is to go to extremes in the matter of curvature, either spending too much money to obtain easy curvature, or, when convinced that that is impolitic, going to the other extreme, introducing recklessly more and sharper curvature than there is any real necessity for; in both cases alike failing to perceive and utilize to the utmost the topographical possibilities.

881. It may at first sight appear to follow from the aggregate of this summary that there is little reason to fix any minimum limit whatever to the radius of curvature except the physical limit of the capacity of the locomotive, and this is so far correct that it is entirely indefensible to START OUT UPON SURVEYS with a limit determined in advance, or to adhere to a limit at every point because at all but one or two points there is little difficulty in so doing. If at such exceptional points a large expenditure is necessary to adhere to it, the expenditure should not be made without a correspondingly good reason. In such a case we are justified in making a moderate additional expenditure for the mere sake of a uniformity which may prove advantageous for operating certain engines or for certain high speeds; but it should in general be a very moderate one.

882. In view of the ever-present danger of overloading the capital account of new enterprises, the better course in such cases is to build a light bold line for a short distance, laid out with the idea that it may be subsequently improved if desired, and if means exist for doing it, in the manner elsewhere discussed (par. 283 *et al.*).

Nevertheless, it is not true that the conclusions summarized above do not warrant, under all ordinary circumstances, the maintenance of a reasonable and moderate limit of curvature; considerably more favorable, if their spirit be closely adhered to, than has been adopted without adequate necessity on many lines. For, although each of the conclusions specified, taken separately, does not warrant the fixing of arbitrary limits to be adhered to at large expense, yet they do in the aggregate indicate, as common-sense also indicates, that reasonably easy curvature is a matter of much absolute although possibly of small relative importance.

883. The true conclusions to be drawn may perhaps be better put in this way:

8. That A STANDARD HARMONIZING WITH THE NATURAL TOPOGRAPHICAL CHARACTERISTICS AND READILY ADAPTABLE TO THEM is the only right and proper one, until the topography becomes so rugged that the physical limit of the capacity of the locomotive, of the class and at the speeds practically required, begins to be approached. This is true both in letter and in spirit, and should be rigidly adhered to. When so adhered to it will rarely cause embarrassment, for there is usually a certain natural limit of radius which can be obtained without much difficulty or expense, and except in extremely rugged mountainous regions this limit will rarely be a high one. This implies that the limit should be varied from point to point along the line, as the general character of the topography varies, and the sharp curvature, so far as possible, bunched.

884. In proportion as the natural limit of radius is favorable the justifiable expenditure to obtain a still more favorable limit decreases rapidly, and it can never be amiss to bear in mind that there is no case on record where a railway has been brought to bankruptcy by the expenses resulting from sharp curvature, nor is there any likelihood that there ever will be such a case, while the instances are many where companies have been bankrupted by their expenditures to obtain easy curvature. Hence, since the money of even the richest corporations is limited, and in the case of new roads almost always more limited in proportion to its needs than its over-sanguine projectors have any idea of, true wisdom requires that the available capital should first be devoted to the really important ends—getting close to and well into the large towns, getting adequate terminal facilities, getting low grades, making what is built well, protecting the public and the railway company at once from danger and loss by proper interlocking apparatus at grade crossings, or by under- and over-crossings, [illegible] for some [illegible] makes the largest [illegible] any change in [illegible]

power of the engineer at any cost whatever) the smallest addition to either the safety or economy of operation.

885. The argument in favor of adapting curvature to the natural topography of the country is greatly strengthened by the fact that sharp curves frequently, if not universally, RENDER POSSIBLE LOWER RULING GRADIENTS IN DIFFICULT COUNTRY and often permit the use of otherwise favorable routes which, without this concession to natural conditions, would be wholly impracticable. The writer could readily mention a number of important instances of the kind from his own experience.

886. But because other ends are more important, this is not therefore unimportant. Because it is unjustifiable to expend any large proportion of the available capital for this end, it does not, follow that a very large proportion of the TIME GIVEN TO SURVEYS should not be devoted to it. Almost invariably it should be, and the engineer who finds himself in rough country devoting little thought and time to saving every degree of curvature possible may be tolerably sure that he has fallen into that most dangerous fault—blindness to its undoubted and great disadvantages.

887. It is so important that the proper course in respect to fixing arbitrary limits of curvature should be so plain as to be fully understood, that we may profitably add a word as to the specific manner in which these conclusions are frequently violated, and the error in doing so.

Many thousands of miles on this and other continents have been built on standards of grades and curvature closely approximating to this:

1. No grade shall under any circumstances exceed 60 ft. per mile.
2. No curve shall under any circumstances exceed 6°. BUT,
3. These limits may be freely used in combination with each other; i.e., 6° curves may be inserted in unreduced 60-ft. grades.

This precise standard has been perhaps more used in this country than any other one combination. It was used on the Erie, the Cincinnati Southern, the Chesapeake & Ohio, the Blue Ridge of South Carolina, and a long list of other roads of less engineering pretensions; having been copied from one to another, apparently, without much regard to topographical requirements—perhaps because the round figures and the alliteration of the 6's had a certain charm. Far less defensible combinations have been the rule throughout the vast expanse of the Mississippi Valley from the causes alluded to on page 6—such as 2° or 3° or 4° limits

of curvature with 40 to 80 ft. grades (0.8 to 1.5 per cent); but it should be added that in general the topography favors long radii, and the chief error has been, not the radius of curvature, but the reckless sacrifices of gradients to save degrees of central angle.

888. We have already determined (par. 825) that the use of unreduced curvature on a maximum grade is never defensible. Except that it has been done in such repeated instances and on so large a scale, it would seem incredible that any one could spend large sums of money to keep curvature down to 6°, and grades down to 60 ft. per mile, and yet pile one upon the other freely, giving in effect a 75-ft. grade. We may more clearly see the folly of it by an example from humble life. Suppose some plain country farmer should find that his team could just draw him up a steep hill through mud a foot deep, and should forthwith draw two conclusions—that it could not draw him up any steeper hill without any mud, nor through any deeper mud without any hill: should we not think the man less intelligent than the beasts he drove? Yet this is precisely what has been done, and to some extent is still done, on thousands of miles the world over, by engineers of standing.

889. Passing this error as no longer likely to be committed, let us consider the propriety and effect of the joint standard of 60 ft. per mile and REDUCED 6° curves maxima:

A 60 ft. per mile grade is 1.14 per cent. If we may use 6° curves on such grades by reducing them to 0.96 or 0.84 per cent (0.03 to 0.05 per cent per degree compenstion), which is the largest compensation used by those who adopt such standards, WHY should we not feel free to use some sharper curves with more compensation, or on a dead level, if we can thereby save some money to put where it will do more good?

890. The answer can only be one of four reasons:

1. A 7° or 8° or 10° curve of equal angular length will be so much more costly in wear and tear, that on no single curve can the saving in cost for construction pay for the loss therefrom. Or,

2. A few such curves, even if fully compensated, will in some unexplained way so limit trains that the same engine cannot do the same work. Or,

3. They will cause such loss of time from slowing up (and certainly require slowing up) that a loss of speed involving greater loss of traffic than the value of any possible saving will result. Or,

4. They are so exceedingly unsafe to operate, compared with a 6°, that in no case can the additional danger therefrom be repaid by an adequate economy in construction.

891. There is no escape from accepting one or more horns of this double dilemma if such a standard is to be justified at all; and probably no man would have the hardihood to attempt to maintain any one of them for explicit reasons given. It is not thus that such utter and evident blunders as this—which simply to state their nature clearly is to condemn—have come about; but rather by the vague process of jumping at conclusions outlined in par. 245—that "the —— Railway is to be first-class;" that "nothing over 6° curvature is generally considered first-class;" *ergo*, etc. etc. The fact that most of the great trunk lines have 8° to 10° curves (Table 116), and that the lines which have set up such purely arbitrary standards have been to a very large extent lines of a secondary class, increases the obviousness of the error committed.

CHAPTER XX.

THE CHOICE OF GRADIENTS, AND DEVICES FOR REDUCING THEM.

892. We have seen clearly enough in preceding chapters that the gradients are the one thing among the purely engineering details on which the engineer should concentrate his attention, subordinating them only to the end of reaching the sources of traffic, if even to that.

We have seen also, in Chap. XVII., that the use of assistant engines for short distances with low ruling grades elsewhere, is generally preferable to a uniform through grade, both topographically and financially; for the reason that, do the best we can, a uniform grade must usually approximate pretty closely to the rate of the pusher grade if it passes over the same summit, and by adopting it we throw away the advantage of the low grades on all the rest of the line, which may be had, as it were, for nothing.

893. Having recognized these abstract truths, however, the next thing is to apply them, and here we pass beyond the point where specific instructions can be easily given, since the circumstances will vary on every line. A great part of the danger of error has been overcome when the comparative importance of the various details has been realized, but even with that advantage the inexperienced engineer is almost certain to conclude that a certain grade is the lowest attainable, when with longer practice, or more skill, or harder work, or less self-confidence, he would readily obtain grades a third or a half lower at the same cost, and not unfrequently at less cost.

894. There is, however, one general rule, which directly results from what has preceded, and which comes so near to being an infallible guide for the correct projection of lines in the field that, as a rule, the engineer should follow it strictly, deviating from it only for very good reason, viz.:

Follow that route which affords the EASIEST POSSIBLE GRADES FOR THE LONGEST POSSIBLE DISTANCES, *using to that end such amounts of distance, curvature, and rise and fall as may be necessary, and then* PASS OVER THE INTERVENING DISTANCES ON SUCH GRADES AS ARE THEN FOUND NECESSARY.

This law is to be applied with intelligence and not pushed too far, but so far as there can be said to be any universal and fundamental law for location, this is such a law.

895. When the higher grades are in danger of exceeding 2 per cent or 2½ per cent, it is to be accepted only with great caution, and anything beyond 3 per cent will be probably bad practice, except in very mountainous country. As a line falls below 100 miles in length the economy of using pushers decreases, and the practical advantage of a uniform gradient increases.

Accepting this general rule as an axiom, our problem then divides itself into two parts:

1. How to obtain the lowest possible low grades.
2. What to do as to the rates of the high grades.

HOW TO PROJECT LOW GRADES.

896. Considering only a naturally low-grade country with no long-continued ascents to encounter, but only a more or less rolling topography, three fourths of almost every line, or of the part thereof lying in such low country, will naturally admit of an extremely low gradient, if some considerable lateral deviations to throw the line into a generally favorable country are considered admissible, as they ought to be, so that such alternates between any two points as those sketched to a rude scale in Fig. 193 are considered as *prima facie* equally eligible. To obtain the same grades on the remaining fourth will often involve some disagreeable sacrifices, especially when, as so often in the Western States, we can take an air-line by accepting 1 per cent or 1¼ per cent grades, if we are foolish enough to do so.

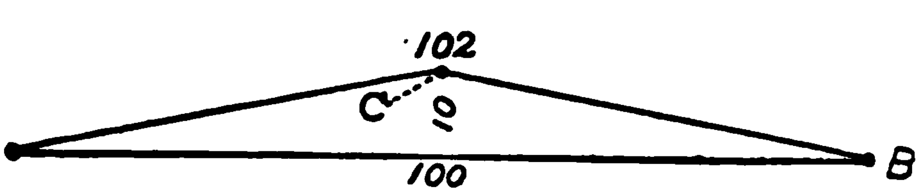


FIG. 193.

These disagreeable sacrifices, however, ought ordinarily to be met, even to the extent of doubling the distance on one quarter of the line if we can thereby reduce the grades to half as high a rate. We shall then

simply have a line 112½ miles long with 0.5 per cent grades, as against a line 100 miles long with 1.0 per cent grades. The former is immensely preferable from every point of view. But usually a smaller sacrifice will make a greater gain.

897. Let us consider, for example, the case of a long, low ridge or swell in a generally flat country, which cannot be run around at all, by any device, since it continues indefinitely. Assume this swell to be three miles across and 50 feet high by the grade-line, after making as large cuts and fills as seem expedient at *A*, *B*, *C*, and *D*, Fig. 194. A tangent over this ridge will give the profile shown in Fig. 195, with two miles of 1 per cent grade and a mile of level intervening. The exaggerated vertical scale makes

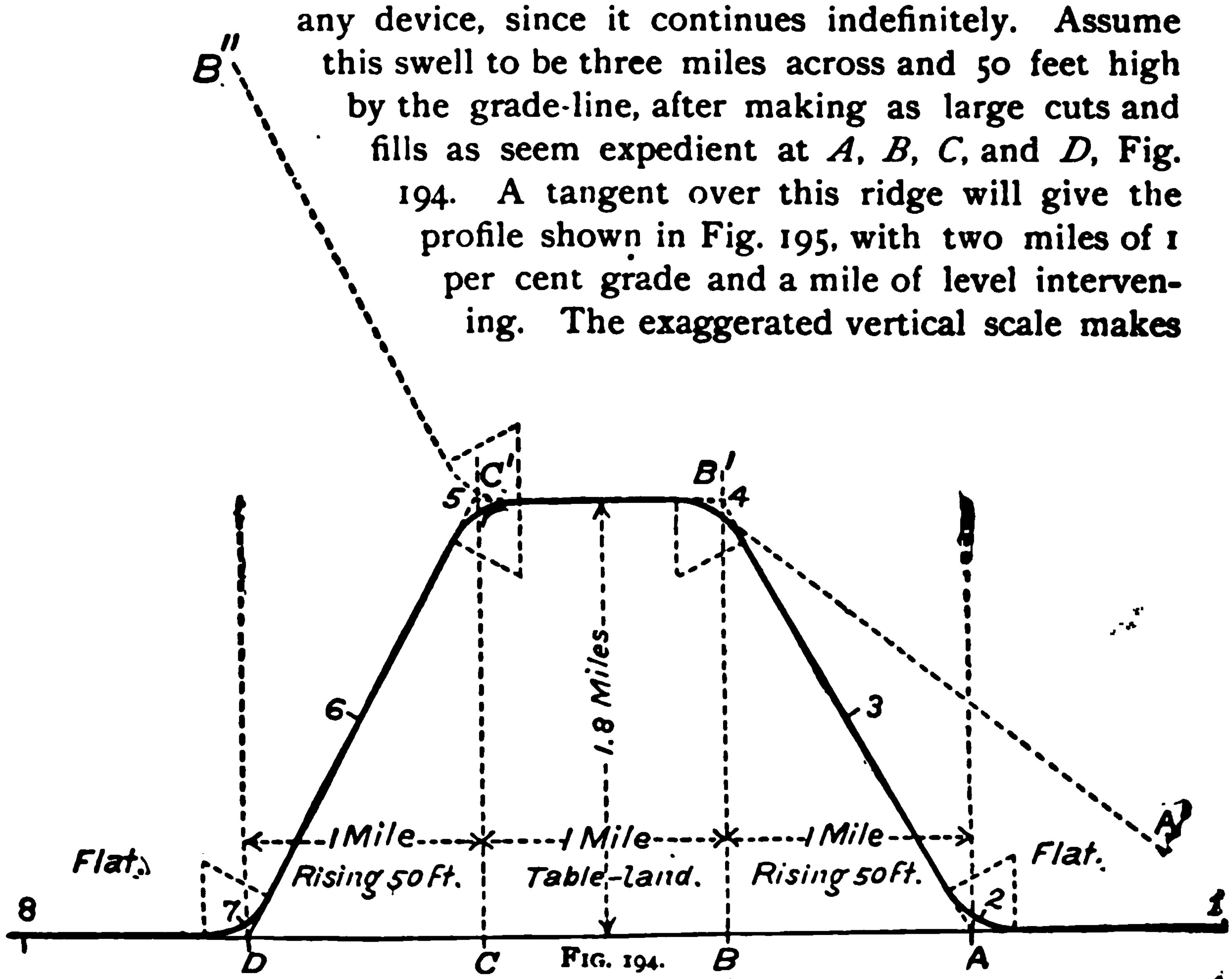


FIG. 194.

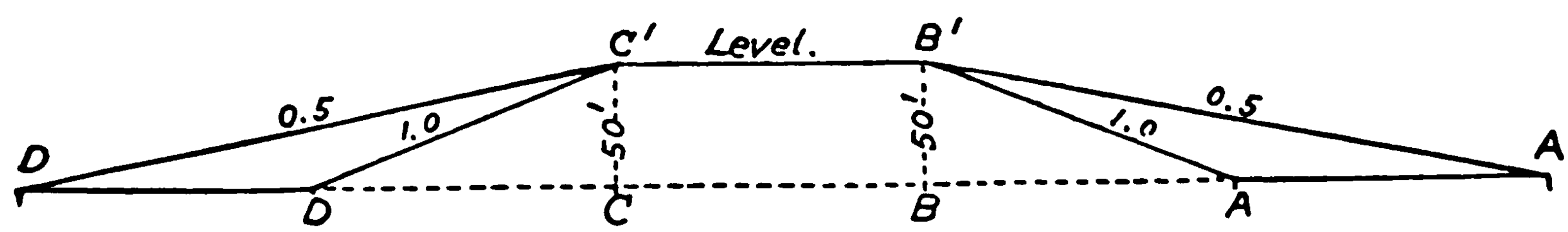


FIG. 195.

PLAN AND PROFILE OF A BREAK IN A LONG TANGENT TO PASS OVER A LONG, LOW RIDGE IN FLAT COUNTRY.

the rise seem considerable, but on the ground it will be hardly perceptible to the eye as an objectionable feature to the railway line.

This is especially likely to be the case because the ground approaching such a rise will not ordinarily be on a dead level, but is more likely

to have about half as steep a rise, perhaps for a long distance back, giving a long 0.5 grade approaching the ridge. This we will assume to be the case, as also that except for this swell, and a few others like it, the 0.5 grade might be the maximum of the whole line. Such conditions have existed on thousands of miles.

898. Now to the eye of a country farmer, and to the eye of many an engineer, perhaps, who may inspect the line during construction, as it runs over the surface of an apparently flat cornfield, this whole region will seem practically a dead level. In the first place, the long 0.5 approach will invariably be taken by the eye to be a level, or perhaps even (by well-known optical illusion) a slight descent. This at least takes off a full half of the apparent vertical angle, and hence of the apparent height of the ridge; and, more probably, there will seem to be a slight dip of the ground toward the ridge and merely a corresponding rise beyond it. In the second place, even if the approach were a dead level, a rise of only 1 per cent in a natural surface seems to the eye a very small thing, especially before the track is laid, so that it would seem ridiculous to turn four right angles "for nothing" and lose two or three miles of distance, at the cost of four such ugly curves through the cornfields as are shown in Fig. 194.

899. Nevertheless, under all the given circumstances, THAT IS PRECISELY THE THING TO DO. The very fact of the long 0.5 approach, which diminishes the visible necessity, makes it the more essential to do so, because it forbids us to resort to the assistance of momentum to surmount the ridge, which otherwise, by approaching the foot of it at 30 miles per hour and reaching the top at 10, would take off (Table 118) $31.95 - 3.55 = 28.40$ vertical feet, and give us, out of our 1 per cent grade, a virtual profile of 0.5 per cent, with something to spare.

900. On arriving at the point *A*, therefore, even if it be with a 30-mile tangent which might be continued for 30 miles more by running straight over the ridge, a sharp turn to the right of something over 60° should be made in the flat cornfield, on about a 3° curve, for the sole purpose of lengthening out the one-mile ascent into two miles, so as to give half the grade. To start the curve *A* farther back, as shown by the dotted line *A′*, so as to diminish the central angle, would do no good, but rather destroy the very purpose of the curve, which is to ***gain distance between A and B*** and not to reach *B′*.

When the line reaches *B′*, another curve of 60° +, in another cornfield, brings it back again parallel with itself, but nearly two miles off. In a mile more, a third curve of 60° + enables it to descend the ridge on the 0.5 maximum by losing another mile of distance, and at *D* another

curve of 60° + brings it back to its proper position, giving in all 2 miles interpolated distance in a distance of 3 miles, 250° of curvature where before there was none, and—what would sometimes be the hardest blow of all—utterly ruining the 60-mile tangent which had been run in exactly straight by foresights only; and all for the sake of obtaining a line so ugly that numerous fingers of scorn may well be pointed at it.

901. And, no doubt, the same end might often nearly be accomplished in such a case, in some more pleasing and economical fashion, as by striking the ridge [illegible] the dotted line *CE*, Fig. 194 [illegible] most of the otherwise waste [illegible] swinging the line at this point [illegible] ground may be obtained [illegible] than on this three [illegible] somewhat extreme [illegible] other sense it is not extreme. [illegible] vantage, if there is nothing to be g[illegible] tween two points 100 miles apart, and [illegible] each way, except for one or two or th[illegible] described, then, as between the air-line [illegible] hundred-mile tangent on 1 per cent gr[illegible] Fig. 194, which will introduce 1500° [illegible] distance, and break the hundred-mile ta[illegible] but give 0.5 per cent grades—the u[illegible] possibility of question in every insta[illegible] greater operating value, unless the line [illegible] can roads, by having a preponderance [illegible] large and competitive. Almost ever[illegible] laying out railways admits of more [illegible] This particular example admits of [illegible]

902. For computing the values [illegible]

Yearly saving by avoiding an increase [illegible] cent in a 0.5 grade, by Table [illegible] train, $4,300 × 5 = . . .

Per contra:

Cost of 1500° of curvature by Table [illegible] train, $0.433 × 1500 = . .

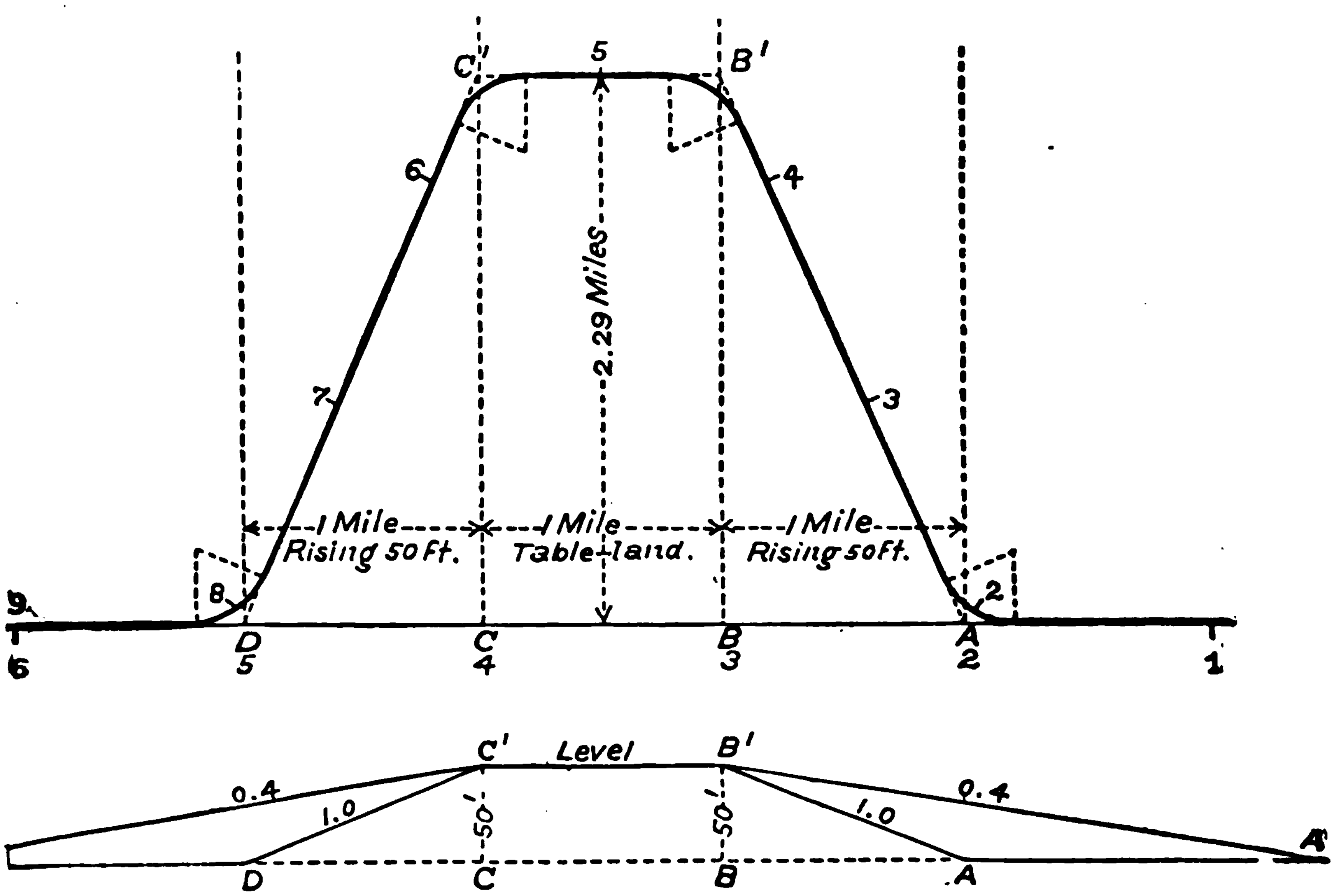
Cost of 12 miles of distance, by Table [illegible] train, $290 × 12 = . . .

Difference, being excess of value [illegible] line, with SIX such breaks [illegible] shown in Figs. 194, 195 [illegible]

This is equivalent to the addition of a capital sum of nearly \$350,000 (at 5 per cent) to the value of the property, or \$3500 per mile, *per daily train.* For ten daily trains each way the line will pay interest on \$35,000 per mile larger valuation.

This assumes that all trains are affected by the difference in gradients, as by the difference in other details. No passenger train, however, would under any circumstances be much benefited by the reduction of grade, so that if one quarter or one half the trains are passenger trains the estimate should be corrected correspondingly. On the other hand, no credit side whatever has been assumed for the loss of distance, whereas there must always be some (par. 227 *et seq.*) and often enough to wipe out the debit side altogether. How the account will then stand is worthy of careful study.

903. This example makes it clear that the assumption may be still



FIGS. 196, 197.—PLAN AND PROFILE OF A BREAK IN A LONG TANGENT TO OBTAIN 0.4 PER CENT INSTEAD OF 1.0 PER CENT GRADES.

more extreme, as by assuming that the attainable through grade, except at a few such points as this, is 0.4 per cent. We then have the conditions of Figs. 196–7, if we are to obtain 0.4 per cent in the same way;

the lateral deviation from the air line being 2.39 miles and the loss of distance at each such point 3 miles, in an air-line of 3 miles. Even in that case three or four or even five such points might be stood before it was concluded to give up the low grade, but at six the loss of distance—18 miles—would be too great, threatening to discourage traffic, and the indication would be very strong that a different general route should be chosen.

904. The general principle which should govern the laying out of low grade-lines or sections of lines cannot be made much clearer than by these examples. The difficulties of obtaining a low grade are ordinarily confined to a few points on the section. Adopt, then, the rate which can be obtained without much difficulty on three fourths or four fifths of the low grade-line or section, and concentrate attention on the remainder with the determination that THE LOW GRADE MUST BE PRESERVED THERE ALSO, if in any way possible. A way will generally appear after careful study, and a very much neater one than that sketched in Figs. 194–197.

905. Much of the lamentably prevalent bad practice in such details as we have been considering comes from the fact that the line is studied in detail only, or bit by bit, and not as a whole, as it should be. If we allow ourselves to think only of the three-mile stretch *AD*, Figs. 194, 196, 198, and think of the consequence of throwing the line out to *C'B'* to pass from *A* to *D*, the mind revolts from it at once. The rectangle *CC'B'B*, Fig. 198, obtrudes itself upon the mind while the project is inchoate, and thus the mind is more repelled by it than when the complete line is laid down, as may be seen at once by comparing Figs. 198 and 194, which are really "similar" to each other, although they do not look it. If the mind were able to take in in due proportion the vastly greater distances on each side which are not injuriously affected at all, while they are made passable for twice as heavy trains thereby, the objections to the deviation would at once begin to fade away. But this the mind cannot do without some assistance, which is one of the many reasons why SMALL SCALE maps and SMALL SCALE profiles should be kept up during the progress of surveys with even greater care than those on working scales.

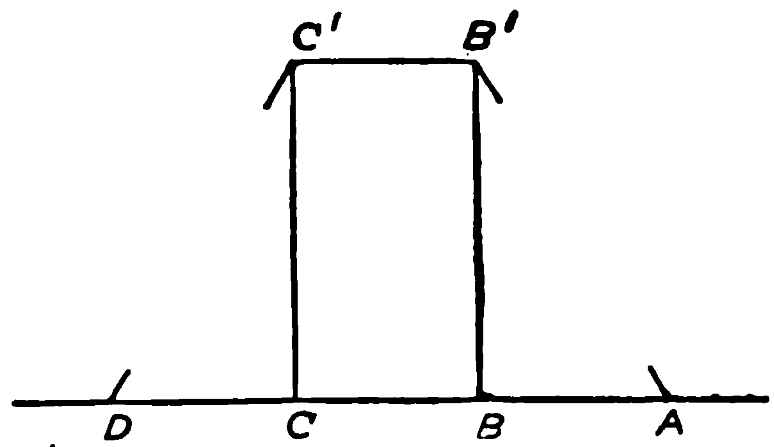


FIG. 198.

HOW TO PROJECT PUSHER GRADES.

906. Suppose that instead of there being five or six such low ridges as that shown in Figs. 194 or 196, scattered irregularly over the division, there is only one, but six times as high, as sketched in Fig. 199. Fig. 196 may still serve as a map of such a point.

FIG. 199.

As between the air-line and the bowed line, IF EACH IS TO BE OPERATED IN THE SAME WAY, the case is not affected in the slightest by the greater height of the ridge and length of the lines *AB'* and *C'D*. The bowed line is much the best. The bunching of the obstacles at one point does make this difference, however, that there is now a rational choice in favor of assistant engines. For any considerable traffic the short line with pusher grades will be very probably the better. The volume of traffic makes a difference in two ways: First, the assistant power can be more exactly adapted to requirements; second, a heavy traffic is almost sure to be largely competitive, thereby diminishing the credit side to the value of distance.

Pusher grades may be divided into two classes, each of which requires different treatment and will be considered separately:

1. Those surmounting low elevations by the easier gradients.

2. Those making long ascents (say over 700 or 800 feet) on rates which must be conspicuously more severe than the through grades on either side, as where $1\frac{1}{2}$ per cent grades or over are required.

PUSHER GRADES ON EASY GRADIENTS.

907. When it is seen that the use of pushers is unavoidable if a low through grade is to be obtained, the first question which arises is: Which is to be the limiting gradient,—the low through grade operated by one engine, or the pusher grade operated by two engines? Ordinarily it will be the pusher grade, for two reasons:

1. The lower pusher grades must be reduced in rate nearly twice as

fast as the through grades to keep the balance equal, as is evident from the following figures, taken from Table 182:

Through Grade....	Level	0.1	0.2	0.3	0.4	0.5	0.6
Pusher Grade......	0.38	0.57	0.76	0.95	1.12	1.29	1.47
Differences.........		0.19	0.19	0.19	0.17	0.17	0.18

For a uniform difference in through grade of 0.10.

It will usually be very much easier to reduce the through grades, complicated by no high elevations, from 0.6 to 0.4, than to reduce the corresponding pusher grade from 1.47 to 1.12, especially as the through grade, from the nature of the case, will be mostly in short undulations; and hence,

2. The influence of momentum (par. 397 *et seq.*, and see also close of this chapter) will frequently assist greatly in reducing the virtual through gradients below the nominal maximum, or can be made to; whereas long pusher grades must be taken at their actual rate.

908. Assuming, therefore, the pusher grade to be the one that fixes the virtual gradient of the whole line or division, all that has been said above about reducing through grades applies to it in an intensified degree. The saving of distance or curvature should be WHOLLY subordinate to the end of reducing the rate of grade to the lowest limits, taking care, however, not to introduce development which adds so much to curvature that the compensation destroys nearly all the gain. A resource in extreme instances may be to introduce a temporary sag in a grade-line, as described in par. 832. Sharp curvature, if absolutely unavoidable, should be used here, if nowhere else.

In this way reductions of grade which are far beyond the apparent possibilities may often be secured. If the engineer who has at last secured what he thinks the best the country admits of, will then throw aside all his preconceived impressions, and start in afresh with the idea that he is all wrong, and might reduce his grade 0.1 per cent or more as well as not, if he went about it right, the chances are many to one that he will not be disappointed, and reductions rising to even 0.3 to 0.5 per cent may sometimes be obtained without a dollar of extra cost, by absurdly simple means, as in the instance described below, and illustrated in Fig. 200, which was the key-note for a reduction of a 2 per cent grade some 15 miles long to a 1.5 per cent grade, with a cheaper line.

909. In the case illustrated in Fig. 200 a located line *aaa* had first been run, on a 2 per cent grade, through a most attractive saddle *A over which the main highway already ran*, requiring a short tunnel of about 1000 ft. The sum

mit of the grade was but a short distance back, and *A* was approached by a much lighter grade; but accepting *A* as a finality, it was utterly impossible to find supporting ground for the grade at a saddle about 4 miles below *A* with a less grade than 2 per cent. The grade was in all some 20 miles long, in two successive sections of 9 and 6 miles, respectively, with some little broken grade intermixed.

Examination indicated (1) that except over this stretch at the head of the grade there would be no serious difficulty in reducing the whole grade to 1.5 per cent, and (2) that the only chance for reducing it above was by gaining developments around the hill *DG*. The very capable and experienced engineer who had made the first location was therefore instructed that the hill must be turned if possible. He ran the line *bbb*, accordingly, to the point *L*, turned a maximum curve *K*, and reported it absolutely impossible to turn the hill, without two very high viaducts over the deep gorge *H* and a tunnel at *K*.

This looked plausible on the ground, if it does not on the map. Standing at *L* there was an abysmal gorge below, a precipitous knife-edge, *G*, of soft rock above, and the smoother side of the hill, *M*, wholly invisible and almost

inaccessible, but known to be very steep. Really, however, there was no difficulty. Running an approximate line *EM* from below, and connecting across the *top* of the hill, it was found that the entire line could be fitted closely to a steep side-hill except for one deep rock cut at *G* so very narrow in proportion to its height that a single heavy blast would remove it all at once. This threw the line nearly 100 ft. lower at *E*, saved the tunnel *A*, and gave much better ground below as well, while enabling the 1.5 grade to be easily obtained.

It is especially important to exhaust all such possibilities on low and short pusher grades (down to the limit which balances the lowest attainable through grade), because the use of two pushers, or still less the breaking up of trains, is rarely expedient, as it often is on the longer and higher pusher grades, which we will next consider.

LONG PUSHER GRADES ON HEAVY GRADIENTS.

910. This second class of pusher grades should ordinarily be studied by themselves, quite apart from the remainder of the line. Their cost, both for construction and for operation, will be a leading factor in the finances of the line, and hence should be a controlling factor. They are sufficiently prominent features in the operation of the line to enable the motive-power to be well adapted to the requirements of the gradients, whatever they may be.

911. These causes favor the adoption of low rates of grade for such a line:

1. As the gradients rise above 2 per cent the loss of net hauling capacity becomes more serious, owing to the weight of the engine and tender, and (for freight trains) caboose, becoming a larger and larger factor, as shown in Table 189, p. 688. From Table 170 we see that on grades differing by 1 per cent the net hauling capacity is—

Grade per cent.	Net tons load for St'nd. American engine.	Per cent (2 per cent grade = 100).	Grade per cent.	Net tons load for St'nd. American engine.	Per cent (2 per cent grade = 100).
1.0	371	193.2	4.0	78	40.62
2.0	192	100.0	5.0	53	27.60
3.0	118	61.46	6.0	36	18.75

2. The lower grade (if obtained by development) not only reduces the cost of operation, but increases the revenue somewhat, by giving a larger mileage. On some costly lines of thin non-

competitive traffic this may justly be regarded as an additional advantage from a low grade. On other lines it might be an almost unmixed disadvantage.

3. As grades rise above 2 per cent or 2½ per cent, such great caution has to be used to keep trains under full control, both in going up and down, as to add considerably to the theoretical disadvantage, both in loss of time and danger of accident.

4. A lower grade will often be found to lie on such ground as to decrease rather than increase the total cost per mile to sub-grade (as we have just seen in par. 909), so that the difference in cost of a low-grade or high-grade line will be at the most not great.

5. A large portion of a continuous descent will often not admit of using a higher grade than a certain rate. It then becomes a regrettable sacrifice to use a higher grade elsewhere on the same descent, although if the grade be long, traffic small, and difference of cost great, it should be done.

912. The Jalapa line between Vera Cruz and Mexico, described in Appendix C and its accompanying plates, is a good example of the effect of every one of these causes favoring low grades. On the first 30 kilomètres (20 miles) of the descent from the summit, although a slightly steeper than 2 per cent grade might have assisted somewhat, a 4 per cent grade would have thrown the line so low as to bring it on much worse ground.

913. The descent from Tepic (see par. 917), on which the spiral occurs, shown in Figs. 207, 208, is a good illustration of the fifth cause above. From the summit down to the foot of the spiral more than the adopted rate of 2.6 per cent could not possibly be used, except by throwing away elevation with level stretches, since that grade brought the line down to the very bed of the stream under the viaduct. The same grade, in the main, fitted the bed of the stream very well, although for 5 or 6 miles it was necessary to hold up above the bed somewhat at some expense. As, therefore, there were only some 5 or 6 miles out of the 30 miles of 2.6 grade (broken by some short unavoidable levels below) in which the descent of 3000 feet to sea-level was made, it would have been an unwarrantable sacrifice to break the grade on the short stretch, where (only by raising it to about 4 per cent) some appreciable economy might be realized, even for the thin traffic expected.

914. The following causes favor the selection of high rates of grades for such sections of line:

1. It usually very much reduces the cost of construction which is probably high at best—a consideration of great importance (par. 29).

2. If the rate of a higher grade can be maintained unbroken, *so that its length is decreased in proportion as its rate is increased*, the total motive-power is not increased (Table 181 and par. 747) even if the total length of the line between termini is not decreased by the higher grade, i.e., if the respective profiles between the two termini are as in Fig. 201. If the lower grade is only to be obtained by interpolated distance, so that the foot of both the low grade and high grade falls at nearly the same point, the advantage in motive-power needed is still more in favor of the high-grade line.

3. The loss by multiplication of trains and train-wages, which is otherwise so very serious on high grades, is obviated in part by using two or three engines per train, which it is not practicable to do with heavy through trains over a whole division. This advantage is to be assumed with caution, however, as within the extreme limits of choice which the engineer has ordinarily before him (say not over 1 per cent in most cases) the same number of engines per train can be used on either the highest or the lowest rate.

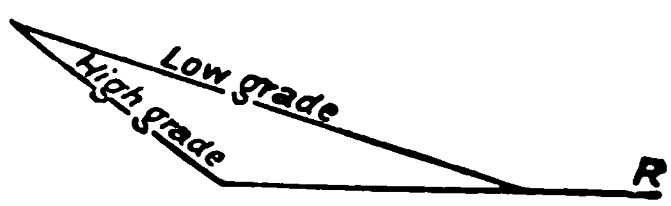


FIG. 201.

915. 4. The case is much stronger in favor of high grades when the low grade is only to be obtained by hanging on a rough side-hill as against lying in the bed of a stream, or with other great contrasts in facilities of construction, as in the St. Gothard Railway, where a low grade was obtained only by the desperate expedient shown in Figs. 202 to 206:—turning spiral tunnels into the solid rock and thus introducing so much pure development between the same termini, so that a higher grade would have shortened the pusher runs almost exactly *pro rata*, and left the same amount of motive-power required for the passage between termini in either case. On the Italian side of the mountain, indeed, these spirals appear to have been an en-

tirely superfluous luxury (see note to Figs. 202–206 on page following them), not even serving to reduce the grades.

Apart from the cost of these spirals, had the grade been higher it would have lain for a considerably larger portion of its length nearer to the bottom of the valley, and hence on better ground.

The St. Gothard line, therefore, furnishes a good example, although certainly not an extreme example, of unjustifiable adoption of low grades. It is mag-

FIGS. 202-3.—PROFILE OF ST. GOTHARD RAILWAY, SWISS SIDE

FIGS. 204–6.—PROFILE OF ST. GOTHARD RAILWAY, ITALIAN SIDE.

[See notes on following page.]

Figs. 202 and 204 are profiles of the bed of the valleys approaching the St. Gothard tunnel, with the scale shown in miles. On the Italian side of the mountain the bed of the stream was broken by cataracts, and it will be seen by the dotted grade-lines plunging below the river-bed that by simply developing the spiral tunnels into straight ones, adding nothing to their length, the same grade up the mountain would have been obtained with a material saving of distance and curvature, and hence, of course, of cost. Such a straight tunnel would start in at the lower portal of the fifth rising curve, near *K*, Fig. 205, and take a straight course through the words "Fig. 205" to a point beyond the limits of Fig. 205, where it would again emerge into the valley, requiring a tunnel of a trifle over 3 miles long, or about what there is now *of tunnel* on the same stretch, saving all the other work and distance. The same is true in substance of the two lower raising curves, or of the upper one at least.

The fact that this throws the grade-line below the bed of the stream looks bad on the profile, but should not be allowed to deceive. The tunnels plunge into the bowels of vast overhanging mountains of solid rock, and can be kept as far away from the stream as desired, if there were need to consider it at all. The only visible gain from the spirals, therefore, was to have the same engineering curiosities on one side of the mountain as on the other.

On the Swiss side of the mountain, Fig. 202, the spiral developments shown in Fig. 203 were essential for the purpose sought, to reduce the grade to 137 ft. per mile. To have followed the natural grade of the valley would have required from 197.5 to 237.5 ft. per mile grades, according to how closely the bed of the valley was followed. By the aid of the long Table 170 we may see how much real economy in motive-power was effected by these developments in taking the traffic from Silenen to the St. Gothard tunnel. Neglecting the actual distance, which it would be unfair to consider, we may say that the length of the mountain grade in miles should be about inversely as the rate of grade. Then we have, for a standard Consolidation:

Grade. Ft. Per Mile.	Comparative Length.	Comp. Net Tons.	Load of Eng. Per Cent.	Comp. Eng. Miles Per Through Ton.
137	100.0	319	100.0	100
197½	69.3	210	65.9	105
219	62.5	184	57.7	108
237½	57.7	165	51.7	111½

In other words, comparing the constructed grade with the 197.5-ft. grade only, in a valley distance of 10 miles, 4.4 miles $\left(\frac{100}{69.3}\right)$ of ***tunnel development*** was introduced with the effect of saving only 5 per cent of the engine-miles necessary to move a car through, and perhaps 2½ per cent of the cost of movement. Such errors result from lack of study of the economic side of railway location. There could be no better illustration of the broad distinction between reducing the rates of through grades and of pusher grades stated in par. 747.

EXPEDIENTS FOR REDUCING THE RATE AND COST OF HIGH GRADES.

916. The following are among the chief resources for obtaining the best results on long ascents. They should always be borne in mind:

1. Hunt for some place on any part of the ascent where, for half its total length or more, a fairly good and cheap line may lie, in spite of surrounding difficulties. FIND WHAT RATE OF GRADE WILL FIT THIS SECTION AND WORK EACH WAY FROM IT, instead of going always to the summit and working down—which is a good rule for small descents, but will often lead one far astray on long ones. In other words, find out what are or ought to be the GOVERNING POINTS, which may or may not be the summit, and work from them. In running a first rough preliminary it is ordinarily best to start from the summit, but on a second line it is rather the rule than the exception that it should not be done.

917. Fig. 207 shows a remarkable example of the advantages of this method, from the location of the lower end of the Pacific Branch of the Mexican Central Railway, on the descent from the city of Tepic to the coast flats. Several efforts were made by various engineers to obtain a practical line, which are distinguished as first, second, and third lines in Fig. 207, but without any very satisfactory result, until, aided by the knowledge gained in the previous surveys, the idea of the spiral line was conceived and pushed to a successful completion, with a reduction of considerably over half in the estimated quantities of the line. The conditions, briefly stated, were these:

The town of Tepic is at an elevation of 915 metres, or 3035 feet, above the sea, and distant only some 17½ miles east therefrom, half of which is a dead flat rising but a few feet above the sea, so that the entire rise would have had to be made on a direct route, within an air-line distance of some nine miles. Descending from Tepic (see Fig. 207), the line first follows the valley of the Tepic River until it diverges therefrom (as it flows in an entirely wrong direction and becomes impracticably rough) and strikes across into the valley of the smaller Ingenio River at the Rincon Pass, marked "controlling summit" on Fig. 207, at an elevation of 2508 feet (795 metres) above the sea.

Up to this point the descent was on less than a 2 per cent grade and offered no difficulty, although requiring some heavy work and affording views of great sublimity and beauty over the rugged and abrupt descent to the coast flats.

In descending from this controlling pass into the valley of the Ingenio River (which is the long stream in Fig. 207 which the line follows below the spiral), the usual difficulty was encountered, that the first descent was exceedingly sharp. In an air-line distance of two miles, from the controlling summit to the lower left-hand corner of the spiral in Fig. 208, there was a descent of some 490 feet. Moreover, the valley of the Ingenio, while entirely practicable for a line in or very near to the bed of the stream, had, for many

miles below the spiral (to near *B*, Fig. 207), abrupt and rugged banks several hundred feet high, of the same impracticable character as those shown immediately below the spiral bridge, Fig. 208, although below *B* the valley became more tractable.

918. Under these circumstances, since it was impossible to descend into the bottom of the valley on any practicable grade, and since, unless this were done, the line must be, for a long distance below the spiral afterward adopted, entirely above the immediate slopes of the valley; to avoid the most excessive work, a comparatively light trial grade, 2 per cent, was not unwisely adopted

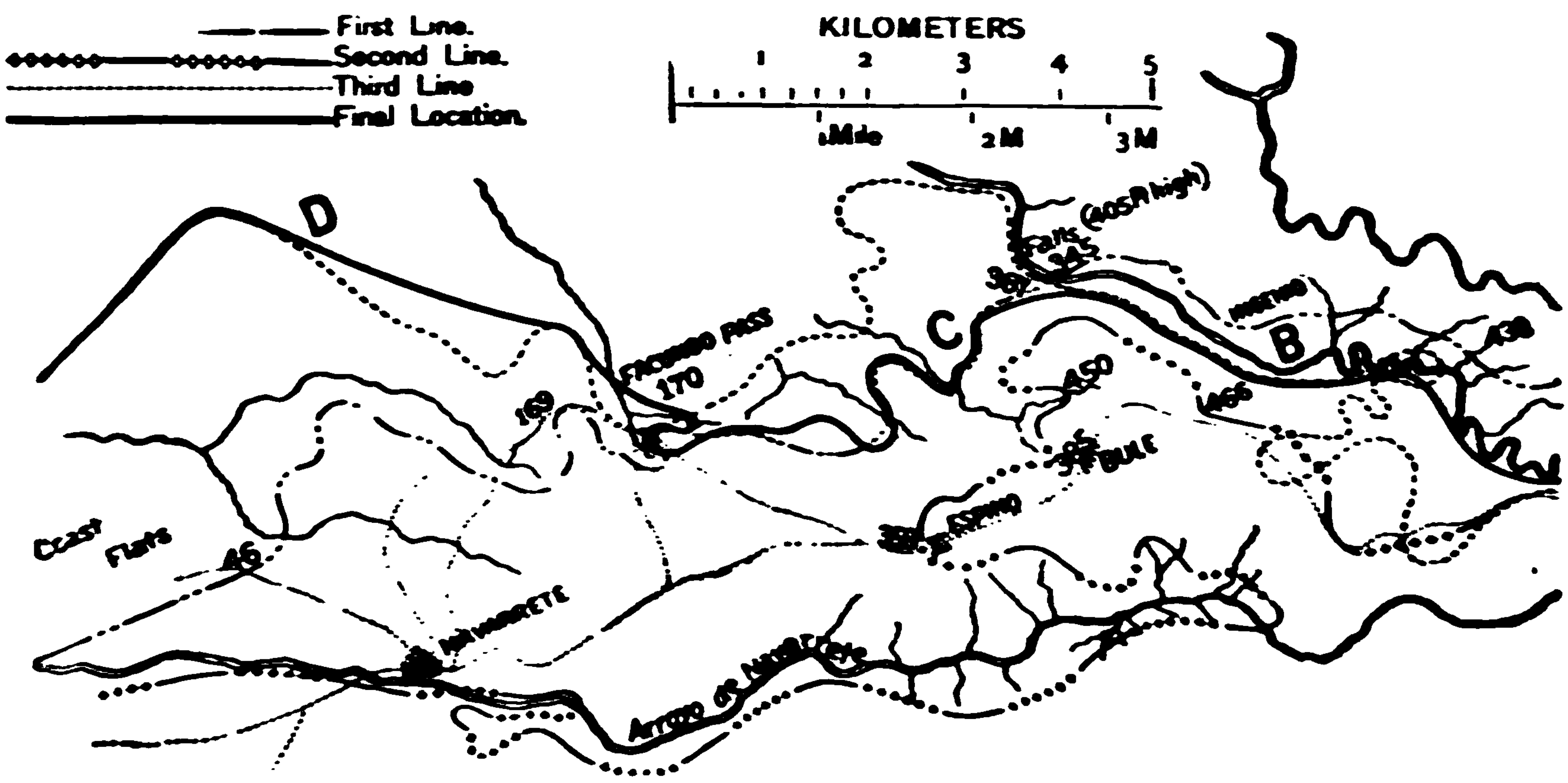


Fig. 207.—Routes of Various Surveys for the Grade descending to the Coast [Black figures give elevation in

for running the three first lines shown by dotted lines on the map. These lines, otherwise differing from each other greatly, agreed in swinging around the area covered by the spiral and close to the latter, although off the area covered by the map of the spiral in Fig. 208. To trace them on Fig. 208, start from near the scale and title and pass thence to the right, then down, and then, at the bottom of the map, to the left, to a point between *A* and *B* on the small scale map, Fig. 207. At this point they were already far above the grade of the spiral bridge, so that they soon left the excessive slopes of the valley and struck comparatively easy work on the narrow ridge lying between the valleys of the two parallel streams shown.

Nevertheless, the work on all three of the lines was excessive, while the low grade required a great amount of otherwise unnecessary development and curvature. Two of these lines were located on paper and profiles made, but no accurate estimates were ever made of them, as the work was very forbid

ding, involving, in spite of the use of 17° curves, a number of tunnels and many retaining-walls and small viaducts.

These facts made it clear, if it had not been before, that the attempt to find a line by starting from the summit as a controlling point, and letting it fall, thence where it would, must be abandoned and a line chosen lying in the bottom of the valley as a fixture and worked from at each end; that being the only place where a really economical line could lie for the entire distance down to *C*, Fig. 207.

A random line in the bed of the stream showed that a 2.6 per cent grade

PLATS FROM TEPIC, MEXICO, ON PACIFIC BRANCH OF THE MEXICAN CENTRAL RAILWAY.
metres. The spiral shown in Fig. 208 is [illegible] shown above.]

(137 feet per mile) was the lowest adapted to it, and in assuming the line to be in this position, and extended from each end (i.e., conceiving the line fixed under the bridge in Fig 208), the ascent thence up the upper small stream was (for the country) mere surface work, and the extraordinarily favorable point for the high crossing (the narrowest for miles) naturally suggested sweeping the line around, through a deep but narrow cut, into the lower small valley, so as to cross over itself by a high viaduct, and thence ascend to the summit. Above the viaduct it follows up the right slope of the small stream shown just under the title to Fig. 208, being on the opposite side from the three previous lines, which chanced also to be somewhat the best side.

It was found on extending the line up to the summit that it left some spare elevation, and this was properly concentrated within the spiral, in order to make the bridge as low as possible

919. There was a possibility of a direct line from Tepic to the head of the

spiral, following approximately the highway *via* La Fortuna, but it was not deemed worth survey, for these reasons:

First.—It was certain that it could afford no better grade, and but little, if any, difference in curvature, distance, and cost.

Second.—The fine water-power of the Rio de Tepic would have been left at one side, with the mills already on it, and the others which were very likely to be placed there—water-power being very scarce in Mexico.

Third.—There was considerable local traffic from La Escondida and points beyond it to the west, which would be lost.

Fourth.—A dull, uninteresting ride would have been substituted for one of the greatest scenic attractions. A chief dependence for the traffic of the Pacific Branch (and for the main line of the Mexican Central as well) being tourist traffic, and much of the remainder of the line being of great scenic beauty, this alone was deemed a decisive consideration.

920. The leading dimensions of the spiral and viaduct were as follows:

Length of spiral, 2,637 metres		= 8,652 feet = 1.64 miles.
(405 + 60 = 669 + 30, with 10-metres station).		
Descent in spiral, actual	53.00 metres	= 173.9 feet.
Descent in spiral, on 2.6 grade	68.56 "	
Loss of elevation in do	15.56 metres.	
Utilized as follows:		
For curve compensation, 303 degrees (at 0.06 per degree)	5.56 metres.	
Spare elevation, utilized for a station ground and water station at south end of spiral	10.00 "	
Viaduct: Length, 200 metres		= 656 feet.
Height, 53 "		= 173.9 "

The height is above the grade-line. Above low-water it was some 7 feet more.

Other resources for reducing the rates of long ascents are:

921. 2. ZIGZAG DEVELOPMENTS, obtained by finding a favorable point for the line to turn a half-circle and return upon itself, often immensely facilitate a favorable result, enabling the possibilities of any favorable section of a long descent to be utilized to the utmost, or enabling the line to keep away from the more serious difficulties. The development on the Jalapa line, Appendix C, is a good example of this device. The privilege of using a sharp curve occasionally is a great assistance to this end, and often a *sine qua non*.

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Fig. 209 is another example to scale of such zigzag or horseshoe development, on the Lima & Oroya Railway, in Peru. The distance from *A* to *B* horizontally is 570 feet, and vertically is 365 feet. The horizontal distance from *C* to *D* is 495 feet, vertical distance 360 feet; length of line from *A* to *D* is 4 miles. The usual rule on this road was to use switchbacks for such developments, as shown in Figs. 218–21. In all these cuts the dotted lines represent tunnels. The curve at Sacrape is 14° 30′.

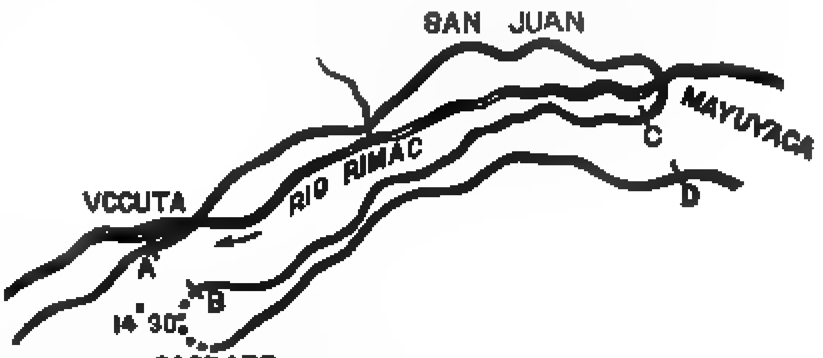

FIG. 209.

922. 3. SPIRALS might be used to great advantage much oftener than

FIG. 210.—BRIDGE SPIRAL.

FIG. 211.—TUNNEL SPIRAL.

they are. A spiral, also sometimes called a "loop," is a doubling back of the line upon itself so that it returns under itself at a lower elevation.

They are of two classes: BRIDGE SPIRALS, Fig 210, in which the upper end of the spiral is carried over the lower on a high viaduct, and

FIG. 212.—BRIDGE SPIRAL ON GEORGETOWN BRANCH OF THE UNION PACIFIC RAILWAY.

TUNNEL SPIRALS, Fig. 211, in which the lower end of the spiral passes under the upper end with a tunnel. Figs. 215–217 show one of the most extensive applications of the principle of spiralling (made possible only by very peculiar topographical conditions) which was ever attempted, but a better line was afterwards found. In the typical bridge spiral the line swings around the slopes of a valley or basin, and in the typical tunnel spiral the line swings around the slopes of a central hill. The tunnel spirals of the St. Gothard line (Figs. 202–206) are also tunnel spirals, in a sense, but of a third class, which does not swing around anything.

923. The bridge spiral on the descent to Tepic, Figs. 207, 208, illustrates the advantage gained by them, which is to make a sudden and great drop at one spot. They are, when well laid out, not costly features, and bridge spirals especially facilitate that most important end of

FIG. 213.—MAP OF SPIRAL ON UNION PACIFIC RAILWAY, SHOWN IN FIG. 212.

getting down into the bed of a stream as soon as it has descended so far from its source that it may be said to have a bed. It is to be remembered in laying out bridge spirals that the height of iron viaducts is a minor factor in their cost (par. 1274). They are a rare feature in location, and must always remain so, but might sometimes be used to advantage where they are not. Figs. 212–214 show the only bridge spiral in the United States.

924. 4. In making a descent into a river valley it is an almost invariable rule to DESCEND *against* THE SLOPE OF THE VALLEY, even at the cost of turning a half-circle as soon as the bottom is reached. The length of the side-hill descent is much decreased. It is still better, if possible, for the same reasons, to descend against the slope of some tributary valley, turn a half-ci [illegible] descend in its bed to the main valley. Figs. 215-217 give an actual instance on a large scale.

In Fig. 215 a descent was to be made from *E*, at [illegible] sea of [illegible] m.), to *A*, into the valley of the Ameca River, at an elevation of 1120 feet (340 m.) above sea, a drop of some 1880 [illegible] an air-l [illegible] to *A* of [illegible] Ameca River lies along the bottom of Fig. 215, flowing to the left with a sharp descent of over one per cent, so that beneath the spirals *FG*, shown in detail in Figs. 216, 217, the bed of the river was only 1020 feet (310 m.) above sea. The tributary *AB* had a

still sharper descent of over 2 per cent, and the circumstances of the location made it clear that the ruling grade on the descent must be at least 2½ per cent. The location shown in Fig. 216 is 3 per cent compensated, about 2.6 per cent actual.

At the left of Fig. 215 was another tributary, *EG*, falling far too fast for any line to follow it directly, but making a very high and steep backbone or knife-edge at *FG* of solid basaltic rock, overlaid for the most part with a thick surface deposit of volcanic tufa, or *tepetate*. This knife-edge had excessively steep slopes on both sides, as will be seen from Fig. 216, extending down to the river-bed 1000 feet below, and had the further remarkable peculiarity that the sides swelled in and out, making it very thin at points and thicker at others. These unusual topographical features made conveniently possible such an unparalleled series of spiral developments as are shown in Figs. 216, 217, which took very kindly to the natural surface, so that they could be executed at very moderate cost, as the minutely accurate topography of Fig. 216 will show.

925. Under these circumstances there were two possibilities for the descent from *E* to *A*: First, the line *EDCBA*, which subsequently proved to be by far the best; and, secondly, the line *EFGHA*. Influenced by the ease with which great development could be obtained in a small space and at small cost at *FG*, Fig. 215, as shown in detail in Figs. 216, 217, the latter line was examined first; the only useful result of this work having been that it is possible to present to students the instructive study in location shown in Figs. 216, 217, where six successive spirals are shown (the lowest one finally abandoned), accomplishing a descent of 613 feet (187 m.) within a horizontal distance of about 1800 feet, measuring from the highest to the lowest points shown on the map. The developed distance between these same points was 4.45 miles (7.18 kilos.). Measuring from the nearest points of the first and fifth spiral, a descent of 426 feet and a development of nearly 3½ miles was obtained between points only 558 feet apart horizontally. The lowest (abandoned) spiral gave a further development of .855 mile and a descent of 125 feet within a horizontal distance of 263 feet. A striking feature of the development was the two-story iron viaduct outlined on Fig. 216; a precipice over 200 feet high for a short distance at one point enabling the line to pass twice over the same viaduct at elevations 100 feet apart.

The value of such a feature as an advertisement and attraction to trave for a line which must in any case be largely dependent on tourist travel, was an element not to be despised; but it was all but certain that the true location must have been by the northerly route, as was found to be the case· for (1) the stretch *ED* lay along the natural surface; (2) the stretch *AB*, accomplishing nearly one fourth of the rise, lay in the bed of a tributary stream rising nearly as fast as the desired grade. All that was necessary by this route, therefore, was to find ground on which the descent from *D* to *B*, and the

turn at *B*, could be made. In other words, granting that a turn at *B* could be made, more than half the descent could be made on very easy ground. Examination showed favorable points at *B* and *C* for the turn, and a very favorable location was obtained for the entire descent. This line also had engineering and scenic features of great interest; chief among the latter being a gigantic natural obelisk of stone, produced by erosion, 572 feet high, and pierced through the centre of its base by a tunnel 279 feet long.

926. Besides these four, which may be called normal expedients, there are the following, as difficulties multiply:

5. SWITCHBACKS: the proper laying out of which, and the arguments in favor of using them when so laid out, are described in Appendix C.

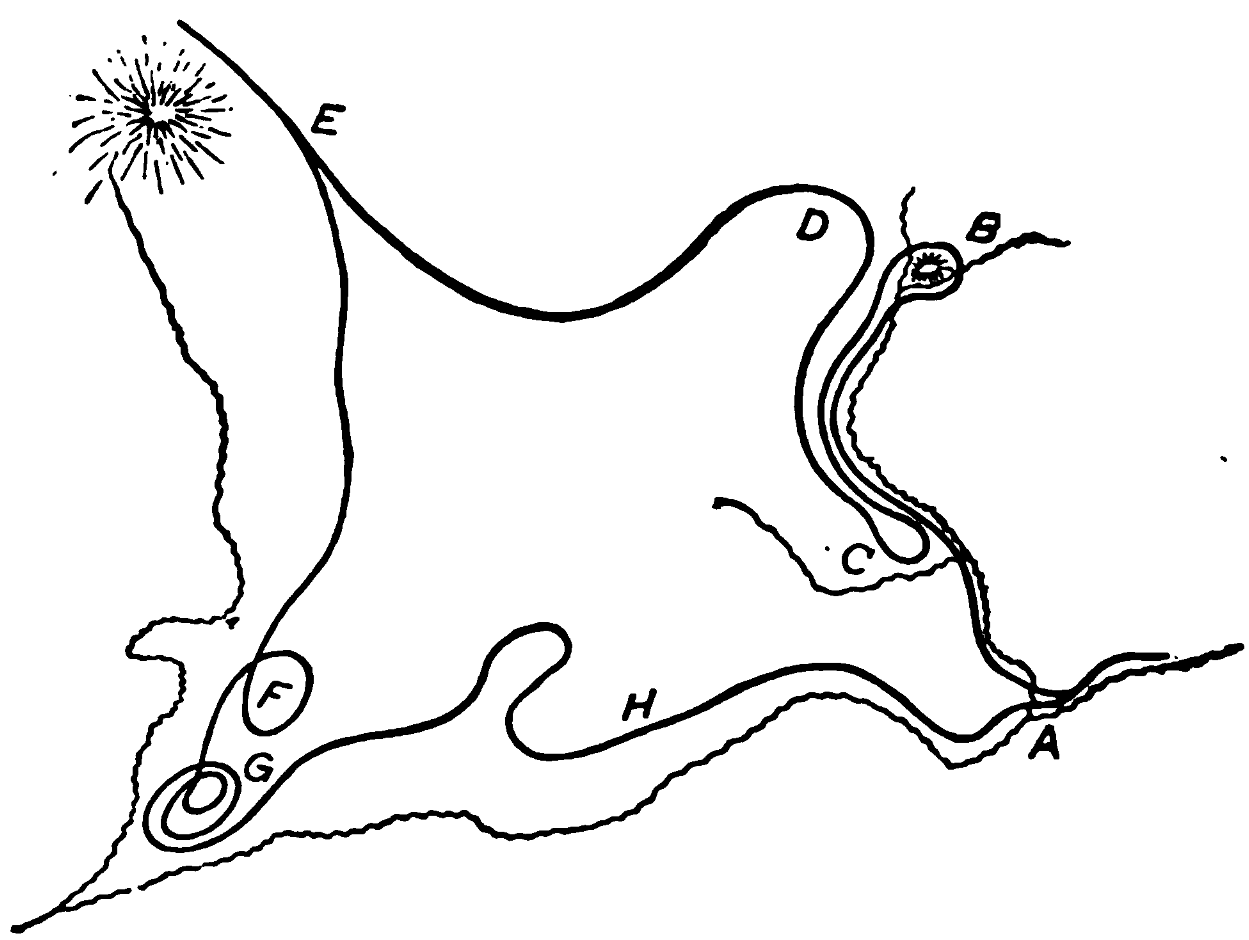

FIG. 215.

When descents of over 1000 feet are to be grappled with, and often with less, the writer believes they should be used much more freely than they are, if laid out in the way described, so that the stop and reversal of the direction of motion involves no loss of time or power, either theoretically or practically. If laid out in the ordinary way they are far more objectionable. Their effect to reduce the cost of construction is very great, and there is no necessary loss of time or power from the stop. Figs. 212–214 show a locality where well laid out switchbacks would have been vastly more economical, and have given better results in other ways.

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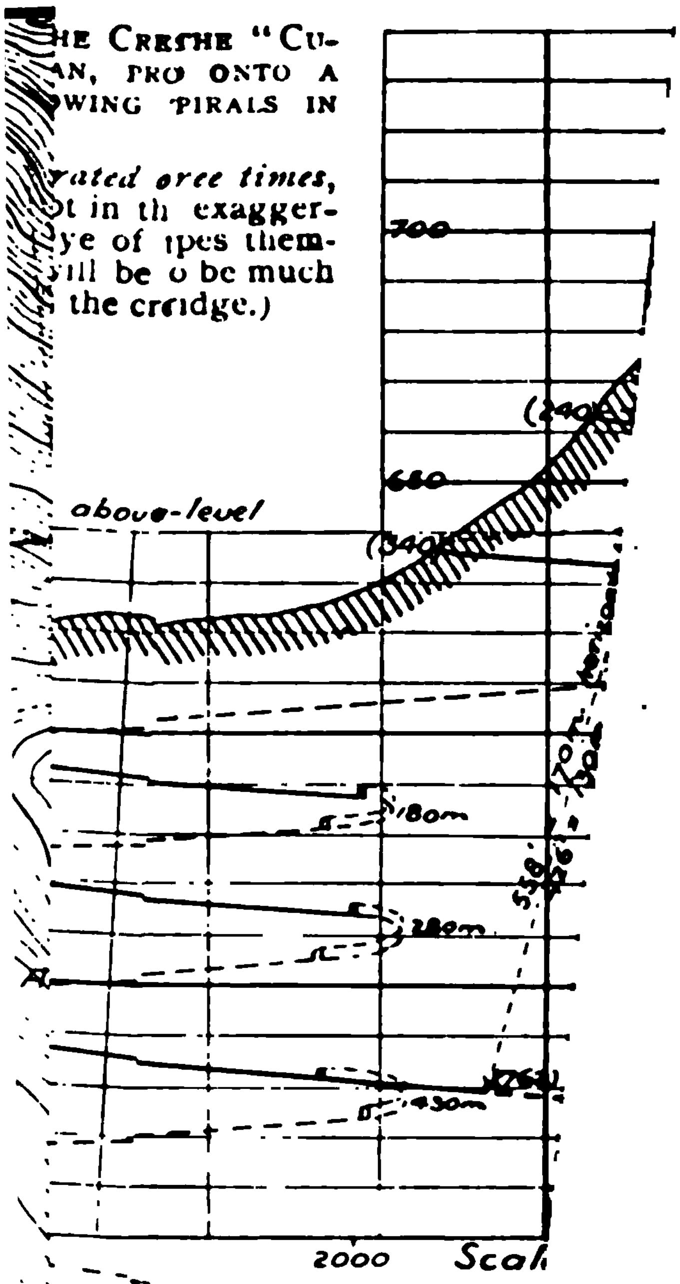

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927. The following Figs. 218 to 221 are examples of switchbacks from the Lima & Oroya Railway in Peru. They give an idea of the advantage which they give for location, but they were not properly laid out to reduce the disadvantage of a stop to a minimum. Fig. 218 shows a rather unusual and unfavorable method of laying them out, the switchbacks being usually in pairs, as in Figs. 219–221, and as near together as possible, so as to

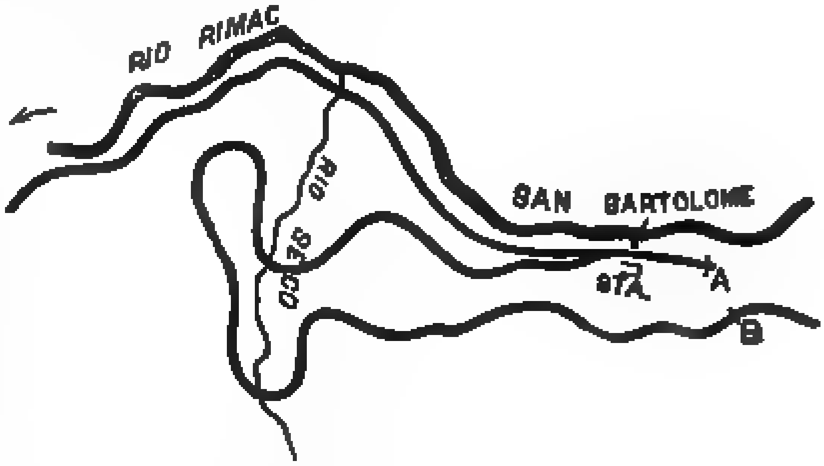


Fig. 218.

reduce the distance on which the train runs backward to a minimum. From *A* to *B* is 3½ miles by the line. In an air-line they are 855 feet apart horizontally, and 545 feet apart vertically

From 1 to 2, Fig. 219, is 5 miles by the line and 1¼ ...e horizontal distance between ...rtical distance 625 feet. The ...en *E* and *F* is 465 feet, vertical ...g an average slope steeper than 1 to 1. Many such places were entirely inaccessible to bipeds, and the line was only located by making as careful topographical maps as possible, projecting a location, and triangulating in points on it for beginning construction. ...illos," or "Little Hells," Fig. ...es for some distance, with a between two walls of rock that ...y to a height of 2000 to 2500 ...nder these high points the line crosses the river on a bridge a height of 165 feet above the ...another tunnel.

Fig. 219.

From 1 to 2, Fig. 220, by line of road is 4¼ miles, comprising eight tunnels. An air-line from 1 to 2 is 1¼ miles. The horizontal distance from *A* to *B* is 445 feet, vertical distance 310 feet.

Fig. 221 shows another very peculiar development—a combination of switchbacks and horseshoes. From A to B by line of road is 4.9 miles, by air-line 1.6 miles. This portion of the line has 1776° of curvature—an average of 362° to the mile. From C to D the horizontal distance is 730 feet, vertical distance 570 feet. The profile in this vicinity was not inappropriately known as "Gothic."

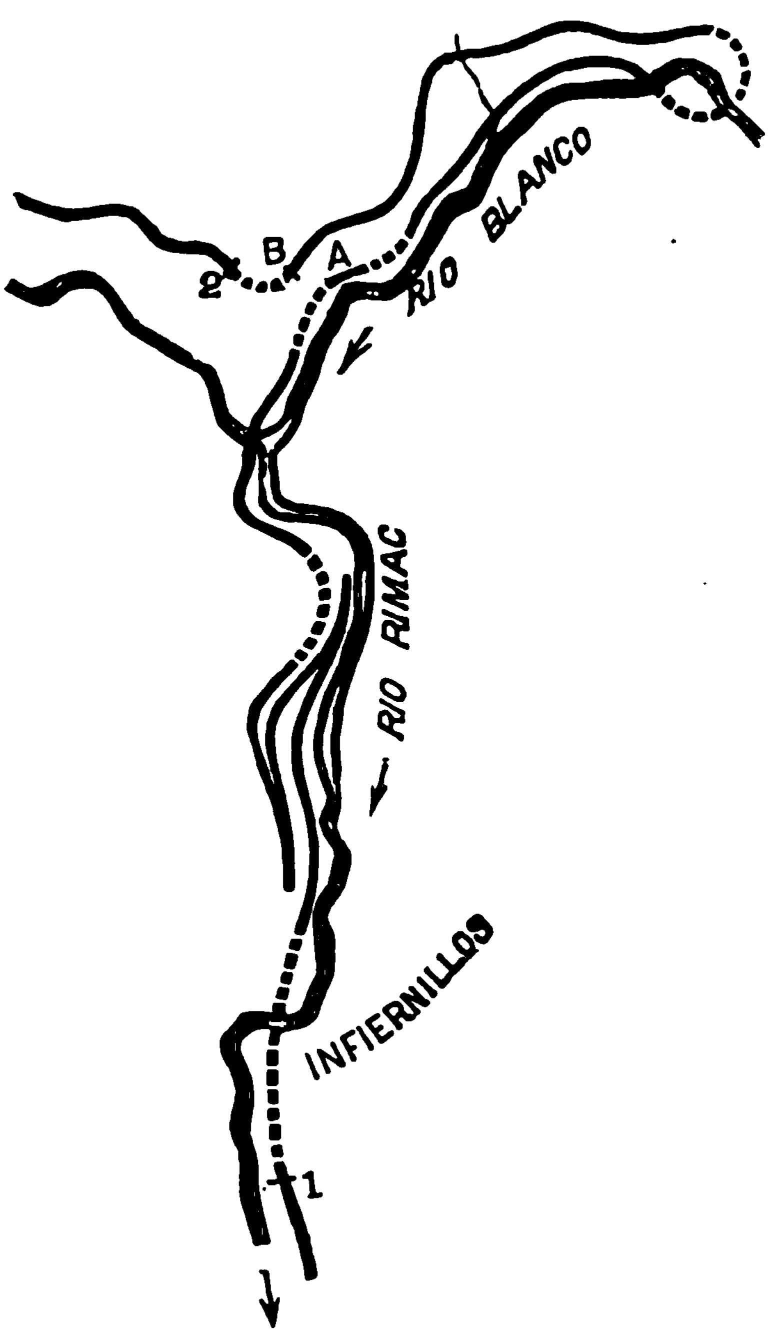


FIG. 220.

These maps taken together will indicate, what is the fact, that even in the roughest country there are certain locations where zigzag developments are more economical than switchbacks, and others where switchbacks alone are practicable, without the heroic expedient of spiral tunnels.

928. 6. INCLINED PLANES AND CABLE TRACTION.—This device, in a crude form, antedates the locomotive itself, and was at first the almost universal resort for dealing with what were then considered high grades. It is still used to some extent, but early passed out of general use as an accredited auxiliary to railway transportation. We may admit that this at the time was wise and right, and still regard the device as one deserving of a recognized standing at the present day. In all probability, within a few years, it will be much more used than it is now for moving large traffic over high elevations.

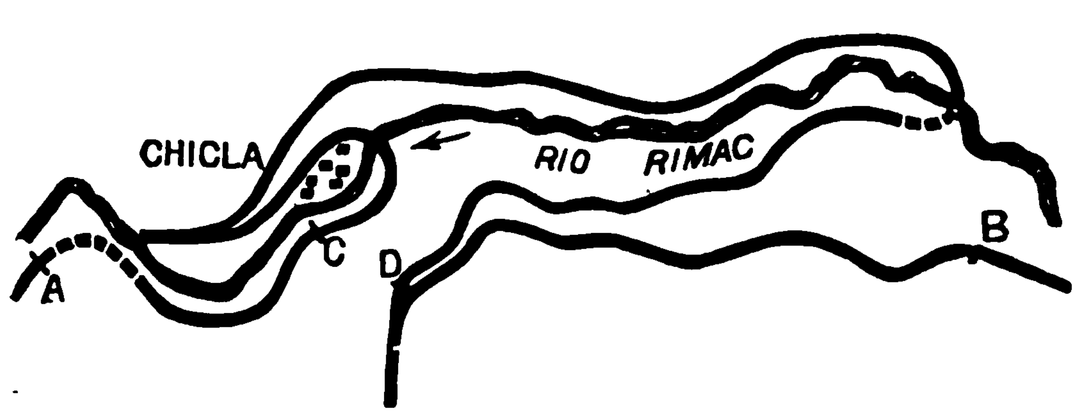


FIG. 221.

929. The arguments against the use of planes are these:

1. It introduces a break in the continuity of the movement of traffic—an argument of minor importance which must always exist in some degree.

2. The power and working force necessary to operate the planes must always be on hand and available, at nearly the same cost whether working or idle, and possibly a good part of the time idle.

This was a very serious matter in early days when traffic was light, but it grows less so as the movement of traffic becomes so great as to approximate to a steady stream of cars—a condition which exists on many lines now operating steep grades with locomotive power. It was a leading factor in causing the abandonment of planes in the early days of railways; hardly subordinate to the following, which was perhaps alone decisive:

3. Formerly, planes operated by stationary power were necessarily short, straight, and on a uniform gradient. This made it essential topographically, even if it had not been mechanically, that the planes should not be long, but that a number of them, separated by intervening stretches of "level," should be used, greatly increasing the awkwardness, delay, and expense of the process.

4. A certain element of danger from runaways and breakages existed and still exists, which was, however, not a serious nor governing consideration, even when the only cable was a hemp rope, as in the early planes at the Alleghany Portage on the Pennsylvania State canal and railway system, and it is still less so now.

930. On the other hand, besides the advantage of the vast increase of traffic which would enable stationary power to be constantly employed at many points, the perfection to which the cable system has been brought in recent years has greatly changed the conditions of the problem, and favored the use of well-designed inclined planes in connection with railways. Passing the question of how they should be designed for the moment, the arguments favoring the use of inclined planes of whatever type are these:

1. The great expense is saved of lifting the ponderous motor itself up and down hill. Assuming every engine to be fully loaded, and assuming a light Consolidation engine with tender and caboose to weigh 80 tons, we may deduce from Table 170 the following Table 189, showing the proportion of the total power exerted which is thrown away in non-productive work on the motor.

2. The power is not only wasted in the proportion shown in Table 189, but is more costly per horse-power for several reasons:

(*a*) The fuel burned per horse-power is much greater than in a good and powerful stationary engine (Table 168, page 531).

(*b*) As one stationary engine does the work of from five to thirty

locomotives, there is a corresponding saving in maintenance of machinery and in wages of engine- and train-men.

TABLE 189.

PROPORTION OF THE DEAD OR WASTE WEIGHT (OF ENGINE, TENDER, AND CABOOSE) TO THE TOTAL PAYING WEIGHT (OF CARS AND FREIGHT) ON VARIOUS GRADES.

[An addition of 5 tons has been made to the weight of an average Consolidation in Table 170, as better corresponding to the more recent practice (Table 129), and a corresponding subtraction of 5 tons from the load given. In addition, a deduction of 20 per cent has been made from the load given, as an allowance for the lighter winter loads, the scant loading of many trains, and light trains in one direction. As an average, this allowance should be larger.]

Grade Per Cent.	Weight in Tons.			Per Cent Weight Engine to Average Paying Weight.
	Engine, Tender, and Caboose.	Train by Table 170.	Do. Average of All Trains.	
1.0	80	706	565	14.1
1.5	"	499	399	20.0
2.0	"	378	302	26.5
2.5	"	299	239	33.4
3.0	"	244	195	41.0
3.5	"	202	162	49.4
4.0	"	170	136	58.8
5.0	"	124	99	80.8
6.0	"	92	74	135.0

(*c*) The wear and tear of track due to the locomotive is saved, which is about half of the whole cost of running them (par. 780). Against this is to be balanced the loss of power by the friction of the rope or cable, but this is comparatively a small percentage on a grade plane, although a very large percentage on level cable railways. The cable friction being constant per mile decreases in relative importance as the grade is higher.

(*d*) The modern cable system possesses several advantages, as notably that of being used on curves, which none of the older and simpler forms of inclined planes possessed.

3. Apart from the cost of the mechanism for operating the planes (which may be balanced roughly against the cost of locomotives), the use of inclined planes will ordinarily cheapen the cost of construction materially, although this may not be invariably the case.

931. If we conceive the normal type of a passage over a summit to be that shown in Fig. 222, the manner of adapting the same summit to the use of inclined planes may be that of either Fig. 223 or Fig. 224. In Fig. 223 the cars are hauled directly up an inclined plane (or, if necessary, up two or more) at *A* and *B* to some point *a* and *b* which is high enough for the cars to descend thence over the entire distance *aCB* or *bCA*, presumably in short trains in charge of one or more brakesmen.

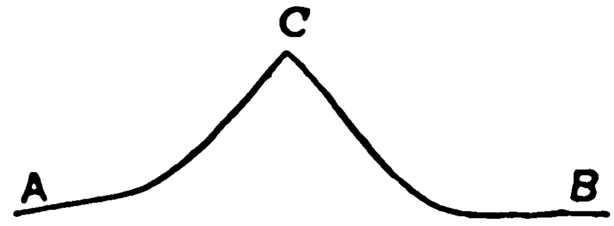


FIG. 222.

The power stored in the cars is thus not lost, by having to be shortly after destroyed by the brakes, but in great degree utilized for propulsion.

932. This economy of power may, under favorable circumstances, be carried still further by the construction of the auxiliary lines *cd* and *ce*, Fig. 224, so as to extend the plan in Fig. 223 to that shown in Fig. 224. By these auxiliary lines, after the cars have ascended the planes *A* and *B* to *a* or *b*, they run by gravity to the points *e* or *d*, where they descend the plane, thus assisting by their gravity to pull other cars up it, and making the only motive-power required (in excess of cable-friction) —that necessary to lift the cars through the distance *da* or *eb*, which is necessary to enable them to run by gravity to the opposite plane. If the distance *ab* were great enough to make it desirable, a nearly level track might be laid, and locomotive-power used, but this involves the disadvantage that the location is more difficult and costly, because the gradients have to be considered in both directions, whereas the duplicate gravity tracks may be laid out on different routes, each of which need be favorable to motion in one direction only.

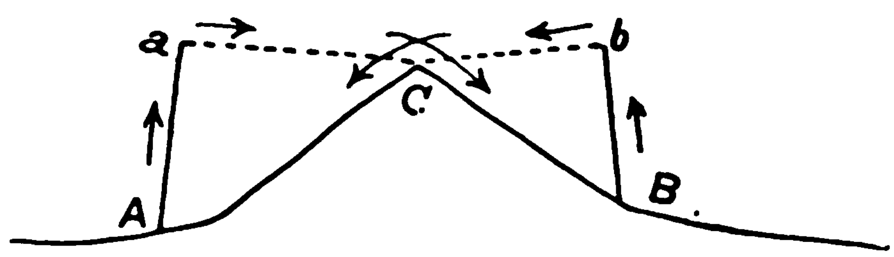


FIG. 223.

933. Theoretically, the system sketched in Fig. 224 completely eliminates the disadvantage of the elevation surmounted, however high, leaving the only loss of power that which would result if the track were vertically projected onto the plane *AB*. Practically, it will of course fall far short of this, but may be made to give some approach to it, and with the privilege of introducing a few easy breaks of line and grade on the plane, which is practicable by the cable system, no great difficulty is likely to arise in laying out long planes advantageously.

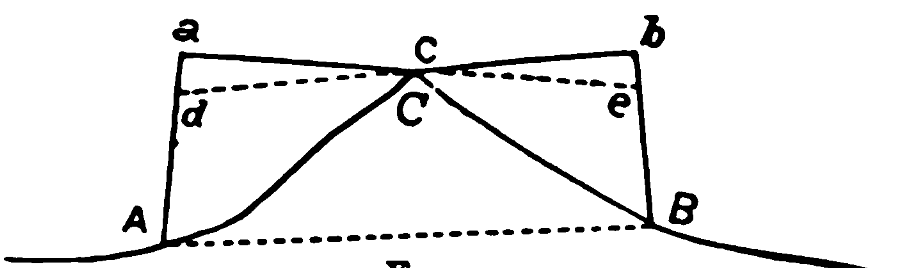


FIG. 224.

934. The modern cable system has not yet been used to any considerable extent as an auxiliary to ordinary railway traffic, although it is tending in that direction. It originated at the city of San Francisco,

from the necessity of supplying street-railway transportation on high grades. In its essence it consists in using a continuously moving and endless wire cable to which the cars are attached by friction-grips, instead of winding up on a large drum a rope, chain, or flat band of metal of the length of the incline, requiring that the engines should start and stop again after taking up each load. The modern system has been brought to great perfection for street use, and has spread very rapidly in spite of the difficulty and expense involved in covering up the cable below the street level. It has been described with remarkable fulness, in all its details of construction and working, in various papers before engineering societies and in the leading technical journals.

935. Circumstances favoring the use of this particular form for railway traffic are: (1) The cable would not need to be covered up and gripped at some disadvantage through a narrow slit; (2) being primarily required for vertical and not for horizontal transportation, the incline could be made steep at the expense of length and speed, reducing the chief source of loss in street service, friction and wear of cables; (3) the grips having to be applied only at the bottom of the plane, and released only at the top, could be made very powerful by duplicating them, or otherwise; the grades at the bottom of the plane could be made favorable for getting the cars quickly under way, and with speeds of not exceeding three or four miles per hour, which would be quite fast enough for economy, the grips could be applied and released by men jumping onto the grip-car for that purpose, so that there would be no necessity for any one riding up or down the plane with the cars.

The system is certainly one of much promise for such localities and conditions, and the necessity of the utmost economy in transportation warrants its careful study, and will probably bring about its gradual adoption, with details adapted to the peculiar requirements.

936. A final expedient for reducing the disadvantages of gradients is the RACK RAILWAY, the most perfect form of which, and the only one promising general usefulness, is the Abt system.

The Mt. Washington Railway, in New Hampshire, designed by Silvester Marsh, was the first example of a rack railway.* The device consists, as its name implies, in a pinion operated by a separate cylinder on the locomotive, which engages in a fixed rack laid between the rails. It

* The Rhigi Railway, M. Richenbach, engineer, was an almost exact copy of every essential detail of the Mt. Washington line, but in a not particularly creditable way was labelled the "Système Richenbach," and is so known throughout Europe.

thus eliminates what we have seen to be the most serious theoretical defect of the locomotive—that its tractive power cannot be increased indefinitely at the expense of speed, but only within narrow limits. In its original form it had many defects which the Abt system eliminates, but its practical utility as an adjunct to the normal operation of railways has not yet been fully demonstrated, and must for the present (1886) be regarded as somewhat doubtful.

937. The salient features of the Abt system are these: The ingenious engaging rack by which a locomotive may approach the foot of a rack grade at some considerable speed, with certainty that the pinion will engage quickly and without shock with the rack; the improved manner of constructing the rack of parallel bars with the teeth staggered; the pinion or driving-wheel, which is constructed in sections, each capable of a slight spring, so as to ensure perfect and smooth contact with the rack; the use of the ordinary adhesion cylinders continuously to lend what aid they can.

On the other hand, there is the complication of the machine, and the difficulty of keeping the rack in working order, especially in the winter in cold climates.*

938. A device for accomplishing the same end as the rack railway in a different way, which has not proved equally meritorious in practice, is the FRICTION-GRIP RAILWAY. In this device two friction driving-wheels engage with a central rail, being pressed against it with any desired force, regardless of the weight on the engine itself. While the device has been used successfully in several special locations, it possesses no features to make it of general utility. It is generally known as the Fell System, and was used at the Mt. Cenis Railway.

DUPLICATE TRACKS FOR PUSHER GRADES.

939. In the main, all climbing done by trains on pusher or high grades is so much clear loss. The power thus stored in the train by lifting it up not only does no good, but costs more money to destroy by means of brakes. It is a peculiar advantage of the use of pushers that this need not be invariably nor necessarily the case, for under certain favoring circumstances it is possible to utilize a portion of the work thus wasted by securing

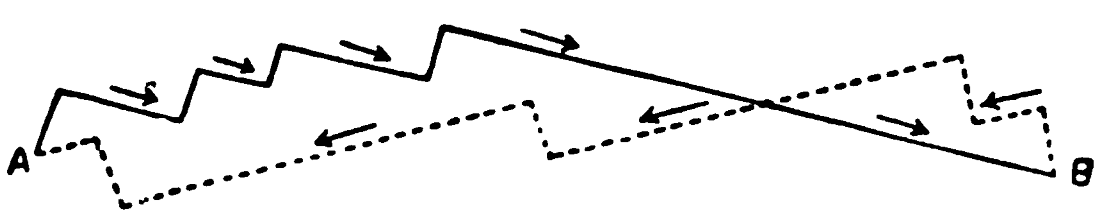


FIG. 225.—TYPICAL PROFILE OF A GRAVITY RAILWAY.

* The Abt system is more fully described in a paper by W. W. Evans, Trans. Am. Soc. C. E., March, 1886.

from it something of the advantages of a GRAVITY RAILWAY, a typical profile of which is shown in Fig. 225.

The gravity railway does of set purpose and to secure an advantage what the ordinary railway only does of necessity as an unmitigated disadvantage; viz., it seeks out certain high elevations, and ascends to them as quickly and by as steep a grade as possible.

This it does for precisely the same reason that coal is put on the tender, viz., TO STORE POWER IN THE TRAIN; only, in this case, the power is ready for instant application without change of form. It is utilized for propulsion instead of being thrown away in wearing out wheels and brake-shoes, by laying out from the high elevation, to which the train is lifted by a plane, a continuous descending gradient, on a 0.7 to 1.0 per cent grade, until the lowest possible point is reached. The train is then hauled up to another high elevation, and the same process continued, giving a profile like Fig. 225. The ascent is made by stationary power; but that does not affect the principle, which is, that, as high elevations must at points be surmounted, it is better to do so by a system which utilizes the work thus done for propulsion instead of wasting it destructively.

940. There is one serious drawback to this system, that cars can pass over the line in only one direction, so that it necessitates an entirely independent return track, however light the traffic. Nevertheless, it has been and is still used to some extent. It originated (in this country) at Mauch Chunk, before the locomotive had fairly been invented, and was afterward embodied in two prominent lines in Pennsylvania, and in a number of smaller ones. One of these lines has recently been abandoned; but for reasons largely independent of the engineering merit of the system; the other is still in operation.

These two lines are:

Pennsylvania Coal Co.—47 miles double track; 4 ft. 3 in. gauge; 36-lb. rails; 23 stationary-engine houses and as many planes, or about one for every four miles. Average speed of passenger trains, 15 miles per hour; freight trains, 10 miles per hour.

Delaware & Hudson Canal Co.—32 miles of double track; 4 ft. 3 in. gauge; 45 to 56 lb. rails; 30 stationary engines and as many planes, or about one every two miles.

The advantage of the plan is that it puts the undulations of the surface which cannot be avoided into the harness, as it were, by making them a necessary part of the system of operation. Moreover, motion in only one direction has to be considered, so that, so long as the train keeps de-

scending, we are in a measure independent of the rate of grade, and economy of construction is promoted.

To balance the disadvantage of having to construct two independent tracks there is a certain economic advantage in a double track even when traffic is light.

941. The extra cost of having to construct two independent lines has undoubtedly been in years past a leading factor in impeding a more general use of this plan, until now engineering practice seems to condemn it, but that under certain exceptional circumstances it might still be advantageously used, hardly admits of doubt. The merits or demerits of the gravity system in its entirety depend chiefly, it is plain, on whether or not inclined planes operated by stationary power are economical as compared with the locomotive. But whether or not the plan as a whole be advantageous, it is plain that, if we have lifted a train by any kind of power to a high elevation, that feature of the gravity plan is economical which utilizes the work thus done instead of throwing it away, and this may often be done with pusher grades, provided the traffic be sufficient to make certain short sections of double track in the immediate vicinity of the pusher grades a desirable feature; which is very apt to be the case, since the mere existence of those grades practically doubles the demand upon the track.

942. Thus, supposing a summit is to be passed over from one valley to another, or a plateau of some width to be ascended to and descended from. Ordinarily the profile over such a section would be something like the solid line in Fig. 226, there being certain natural difficulties in getting favorable grades in more than one direction between B and D, so that the whole stretch AE is practically a single pusher run. If, in such case, the grade AB can be prolonged to some higher point and from thence carried on a favorable grade for trains going to E to a junction at some point D, the expense of running pusher engines both ways over the distance BD will be saved, at the expense of constructing the short section of duplicate track $BFCD$.

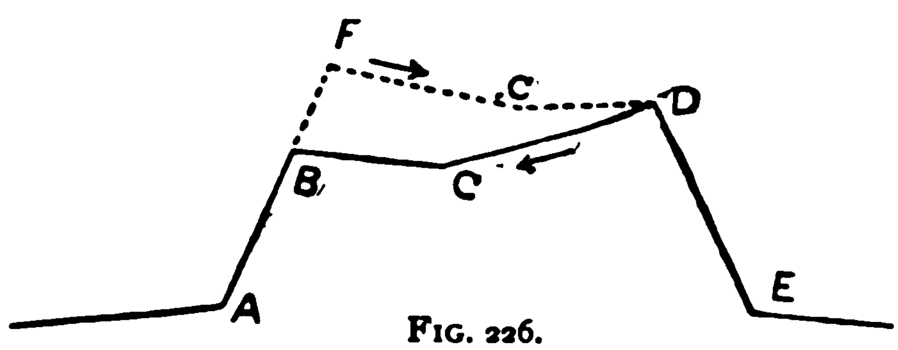


FIG. 226.

943. Again, let us suppose a common case, that we are carrying a line through a valley, a part or all of which has an irregular descent, so that an extremely favorable line may be had for trains running down the valley such as Fig. 227, but favorable grades for ascending it can only be

had with some difficulty and expense. In some cases—not by any means in all cases—it would be possible for a return track to make at once for some high point C on a ridge or crest, and thence to make for the point A with level or descending or but slightly ascending grades, by a ridge line or a different valley line which would be for the most part light.

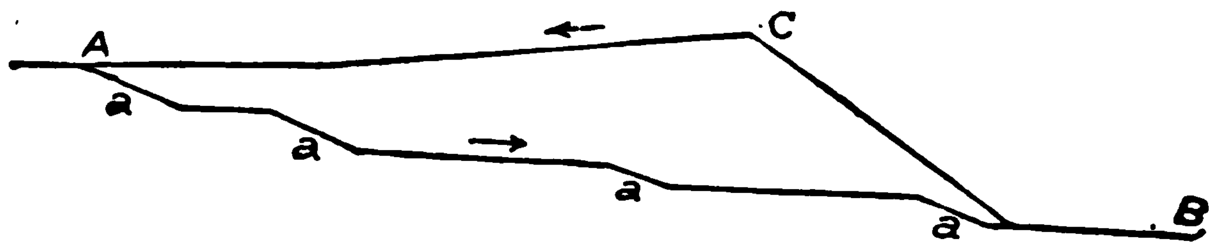


FIG. 227.

Not only is lighter construction per mile of track almost certainly attainable, when this is possible at all, but economy of operation is much promoted, because, instead of having to run short trains both ways between A and B, because of the opposing grades aa, our motive-power is only taxed appreciably on the pusher grade BC, throughout the round trip.

Nevertheless, if there be not traffic enough to require or justify two tracks any attempt of this kind would probably be uneconomical.

944. But after all, a plain continuous descent from a summit to the plain below will ever remain the normal type for location, such devices as spirals, switchbacks, and others being the exception. In all but the most rugged country, say wherever most of the surface to be built over is not bare rock, good and cheap lines can usually be obtained by following these two rules:

First. Do not attempt to secure too low a grade-line by more than a moderate amount of development, remembering that on pusher planes the RATE of grade is comparatively unimportant (par. 747 and Table 181).

Secondly. Do not adopt a limit of curvature too easy for the topography, unless the importance of the line and its probable revenue will certainly warrant it. (See, however, par. 883).

945. The railway system of Colorado is a splendid example of what may be accomplished by the application of these two rules. The fact that it was laid to narrow gauge probably gave courage for adopting such alignment, but it was not at all necessary for its success, as we have elsewhere seen sufficient grounds to believe (in Chaps. VIII. and XXIII). In fact, it is only a question of time when these lines will be relaid to standard gauge without any essential change in their alignment.

"High Line" to Leadville, Union Pacific Railway (Denver, South Park & Pacific). For map, see left end of Fig. [illegible]

There is probably no system of roads in the world which is so well worthy of the study of engineers, because of the marvellous cheapness with which it has been carried through the most forbidding regions, and certainly as good an illustration as any of what has been done in this way is the "High Line to Leadville," on the Denver, South Park & Pacific

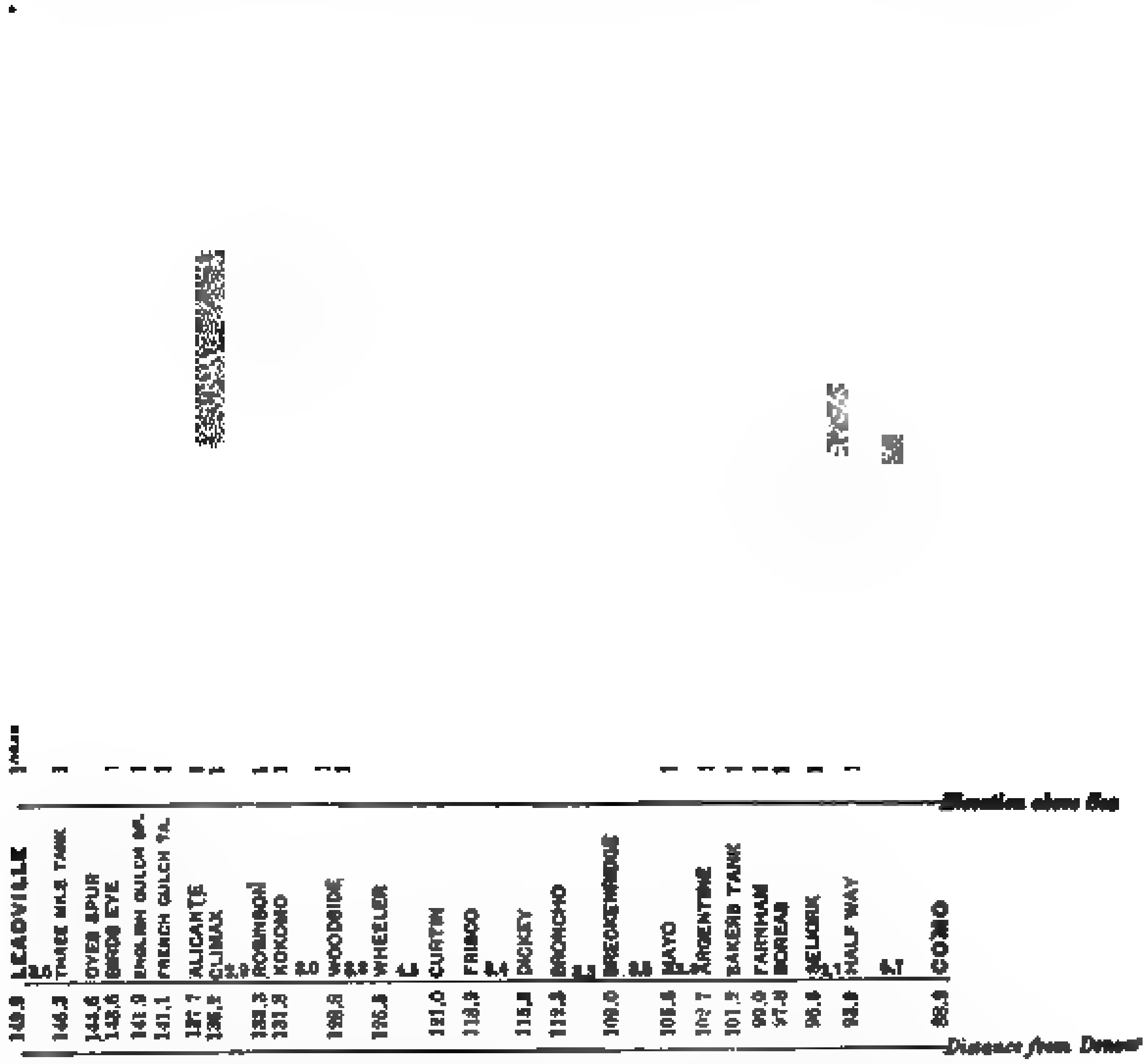


FIG. 230.—PROFILE OF THE LAST 62 MILES OF THE "HIGH LINE TO LEADVILLE."
[Grades indicated in feet per mile. The heavy black line indicates the section shown in Fig. 229, a view from the lower end of which is shown in Fig. 228.]

Railway, now a part of the Union Pacific system. The total cost of this line was, as nearly as may be, $20,000 cash per mile, and this was likewise very close to the cost of the short section shown in the large map in Fig. 229, one of the most interesting views on which is shown in Fig. 228.

For this sum the line was carried over three summits over 11,000 ft.

220.—LOCATION MAP OF THE DESCENT

View in Fig. 227 is taken from the right a to face fig. 230, p. 696

high, two of which are shown in Fig. 230, and for a large part of the remainder of the distance was carried through the narrow and tortuous channel of the Platte Cañon, where long stretches of the work are in solid rock, and where fills were impossible, it being necessary to support the line on retaining-walls when not in the solid. These retaining-walls are among the most interesting engineering features of Colorado. They are dry and very cheap, but very solid, and give no trouble. They were generally the first work started, and were carried along as far as possible before the rock excavation was begun.

946. The probabilities are that in the hands of engineers not driven to economy by necessity, and constructing by what have been regarded as orthodox standards, these works would have cost four or five times what they actually have, while many of them would have been wholly impossible at any cost. In Fig 229 we have clearly before us the chief cause of their economy—the comparatively free use of very sharp curves. On the 11.2 miles shown in Fig. 229 there are in all 127 curves, or 11.3 curves per mile, divided as to degrees as follows:

FIG. 231.—MAP OF THE "HIGH LINE" FROM DENVER TO LEADVILLE.

[The section of line shown by profile in Fig. 230 is indicated by the heaviest line above.]

1°	0	9°	1	17°	1
2°	6	10°	14	18°	0
3°	3	11°	2	19°	1
4°	6	12°	4	20°	25
5°	4	13°	1	21°	1
6°	7	14°	3	22°	1
7°	1	15°	4	23°	0
8°	13	16°	4	24°	24
				$25\frac{1}{2}$°	1
Total	40	Total	33	Total	54

Strike out all curves sharper than 10° (573 ft. radius) from this list, and we multiply the cost by at least four or five at once; besides which, this particular line becomes wholly impossible, since the turn could not have been made around "Nigger Hill" nor in "Illinois Park" in the centre of the view. A far steeper grade or an entirely different route would therefore have had to be chosen. It should also be noted that one rides over these curves without the slightest sense of insecurity or danger, nor have they proved to be especially dangerous in operation. The motion around them is as smooth as around any of the easier curves.

The writer has no definite knowledge as to whether the general route which gave so very bad a profile as this line has was really the best one, and must be understood to speak only of the details of the location.

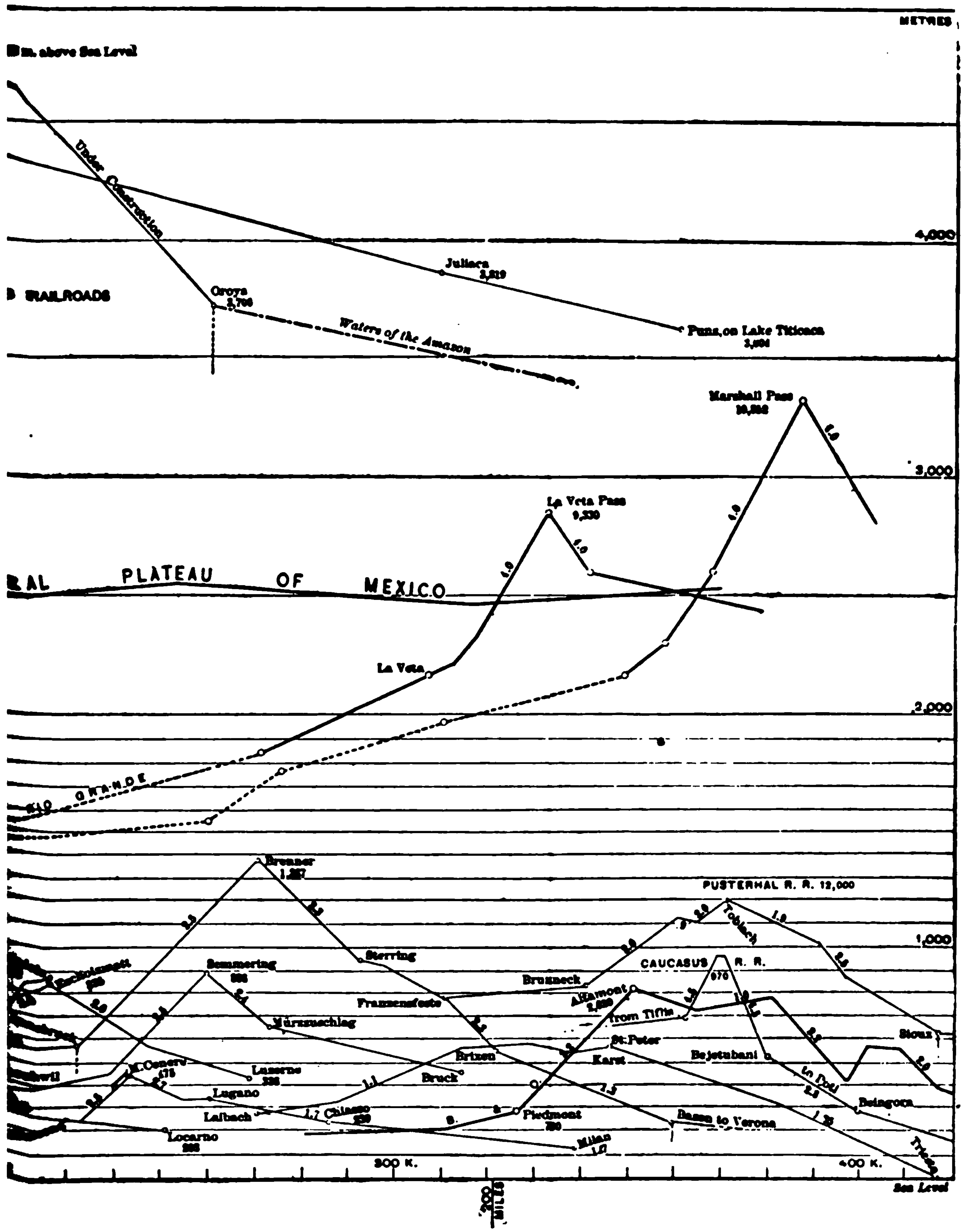
947. Fig. 232 shows comparatively, on the same sheet, a number of the great inclines of the world,* and Table 190, with its long foot-note, adds details of many others, the whole not making a complete list by any means.

* Only the lines shown in comparatively heavy lines on this plate, viz.: The Jalapa line from Vera Cruz, the Denver & Rio Grande, the Pennsylvania, and the Baltimore & Ohio are of the writer's compiling. The remainder has been reproduced from a plate prepared by Mr. W. W. Evans, M. Am. Soc. C. E., to show the Peruvian lines, and he in turn was indebted to European authorities for the admirable presentation of European railways. Comparative distances are of course to be estimated by the horizontal distance, since the exaggerated vertical scale exaggerates the slant length greatly.

A small profile of the Mexican Railway is shown on the map in Appendix C. It could not conveniently be added to this plate for comparison with the Jalapa line. Its general nature will be indicated by projecting a 4 per cent grade (parallel with the Peruvian line) from Las Vigas summit to the level of Jalapa, and then continuing down to sea-level with mixed $1\frac{1}{2}$ to 4 per cent grades, with some lost elevation.

FIG. 232.—COMPARATIVE PROFILES OF SOME

[The Jalapa line is



...at Inclines of the World. (See par. 947).

...ed in Appendix C.]

TABLE 190.

VARIOUS GREAT INCLINES OF THE WORLD.

[The body of this table is (with correction of a number of errors) a list given in *The Engineer* of July 17, 1885, as a complete one. The notes beneath give various other and much greater inclines omitted from the list.]

NAME OF INCLINE.	Length of Incline. Miles.	Total Rise. Feet.	GRADE. Av. p. c.	GRADE. Max. p. c.	Maximum Curve.	Length of Tunnels. Miles.
Giovi	6	884	2.78	3.45	4° 20′	2.25
Semmering	13½	1,325	2.13	2.50	8° 40′	2.66
Bhore Ghaut	15¾	1,831	2.08	2.70	5° 45′	2.26
Allegheny	15	1,690	2.13	....	9° 30′	....
Tabor (Chili)	12	1,360	2.15	2.25	9° 30′	....
Kadugannawa (Ceylon)	11¾	1,388	2.22	2.22	8° 40′	.88
Ambagamuwa "	19	2,227	2.22	2.27	19° 0′	.30

[In addition to this list there is to be an extension of the same Ceylon railway which "will also involve a further incline of 12 miles rising 1359 ft., on which an average gradient of 2.15 per cent, with a maximum of 2.227 per cent, will be compulsory, as will also the adoption of curves as sharp as 19°."]

To the above very inadequate list may be added the following, the whole not making a complete list by any means :

Mexican Railway.—Rises 6412 ft. in 53.9 miles, 4 per cent maximum grade (2¼, average), with 325 ft. curves radius (17° 40′) and 16 tunnels. In this distance it also rises 2372 ft. in 12.58 miles, 3.57 per cent average grade and 4 or 5 tunnels.

The air-line distance between the extreme points of this latter section is less than four miles, but it includes the *bota*, or boot, so called from its shape, nearly eight miles long, and rising to a point on the slope of the mountain which to the eye seems almost vertically over the point at which the "boot" began 1650 ft. below, and which is certainly not over one mile distant from it horizontally, giving an outlook which is even more startling to the engineer than to the average traveller.

Oroya Railroad, Peru.—Rises 2352 ft. in 26 miles on 2½ per cent (1 in 40) maximum grade, *to reach the foot of the main grade;* then,—

Rises 12,845 ft. in 71 miles, on 4 per cent grade, with 14½° curves (396 ft. radius), to an elevation of 15,645 ft., with 42 tunnels.

On this line there are several switchbacks (Figs. 217 to 221), but the first thirteen miles rises 2105 ft. without any switchback.

There are one or two other lines in Peru of the same general character, but rising to less elevations.

Among the European inclines not included above are :

St. Gothard.—Rising 2750 ft. in 20½ miles; 142.5 ft. per mile maximum grade (2.7 per cent); 130 ft. average grades. Also rising 2090 ft. in 15¼ miles, with 28 per cent of the distance tunnels, including (on both these inclines) seven spiral tunnels turned into the mountain to gain distance (Figs. 202 to 206).

Brenner.—Rising 2584 ft. in 22½ miles, 132 ft. per mile (2.5 per cent) maximum grade; 114.6 ft. average.

In the United States there are:

Southern Pacific.—Rises 2674 ft. in 25.4 miles; 116 ft. per mile (2.20 per cent) maximum grade; 10° maximum curve; 11 tunnels, including a "loop," or more properly, spiral or helix, 3800 ft. long and rising 78 ft.

Denver & Rio Grande, Marshall Pass.—Rises 3675 ft. in 25 miles, 4 per cent (211 ft. per mile) maximum grade; 24° maximum curve. Height of summit, 10,852 ft. above the sea. Also,

La Veta Pass.—Rises 2368 ft. in 15 miles; same grades and curves as above. Height of summit, 9339 ft.

The lines over Fremont Pass, 11,540 ft. above the sea,—the highest point reached by the locomotive anywhere in the world except in Peru,—and the Tennessee Pass, 10,418 ft. high, are of the same general character.

Another very notable heavy grade on this same road is:

Calumet Mine Branch, Denver & Rio Grande.—Rises some 2700 ft. in seven miles on an eight per cent grade (nearly 416 ft. per mile) with 25° maximum curves.

This unparalleled line is used to bring ore to the Bessemer-steel works at Pueblo, and is operated by one train per day each way. It is undoubtedly the heaviest grade on any regularly operated railroad in the world, although 10 per cent temporary grades (528 ft. per mile) were successfully operated for over two months over the Kingwood Tunnel of the Baltimore & Ohio Railroad by the late Benj. H. Latrobe as early as 1852.*

These latter lines are narrow-gauge, but need not remain so unless they choose.

Mexican National.—Rises 2628 ft. in 17 miles; on 3.8 per cent (201 ft. per mile) maximum grade; 15° maximum curves; with a descent of 1325 ft. in nine miles on a 3.5 per cent grade on the other side of the summit. Laid to narrow-gauge, but expressly built throughout to be adapted to standard gauge. On same road:

Mexican National, Northern Division.—Monterey to Saltillo. Rises 3465 ft. in 54 miles, at an average rate of 64 ft. per mile, most of the rise, however, concentrated on a short portion of the distance on grades of 2½ per cent.

Less important inclines which are for one reason or another notable are:

Tyrone & Clearfield.—A little branch of the Pennsylvania Railroad. Rises 1064 ft. in 10 miles. Tangent maximum, 138 ft. per mile.

Central Pacific.—Rises 992 ft. in 13 miles; 2 per cent (105.6 ft. per mile) maximum grade; 10° curves; eight tunnels.

Northern Pacific.—Rises 1668 ft. at 116 ft. per mile (2.2 per cent) in an air-line distance of 13 miles.

Mexican Central.—Rises 1750 ft. in 19 miles at San Juan del Rio with easy grades and curves and 1650 ft. at Zacatecas.

Among lines located, but not yet built, may be mentioned:

Luckmanier Pass (near the St. Gothard).—Rises on a development of 29½ miles *between two points six miles apart*, on a maximum grade of 132 ft. per mile (2.5 per cent) implying a descent of something less than 3900 ft., with maximum curves of 984 ft. radius (5° 49′).

Mexican Central.—Two lines ascending from the coast to the central plateau of Mexico, one from the Gulf of Mexico at Tampico and the other from the Pacific at San Blas, both of which rise some 4500 ft. on 2 to 3 per cent grades.

* For a full and most interesting account of these and other works by Mr. Latrobe, see *Railroad Gazette*, December 5, 1874.

Vera Cruz to City of Mexico, via Jalapa.—The line more fully described in Appendix C. Rising 7323 ft. (2232 metres) in one unbroken 2 per cent (average) gradient for 72.64 miles (116.9 kilometres) or from an elevation of 600 ft. to an elevation of 7923 ft above the sea.

948. The great effect of fluctuations of velocity to modify the nominal rates of short gradients may be illustrated by the following tests made by Mr. C. H. Hudson, a prominent and able railway manager. The tests are thus described:*

"Recently, for the purpose of testing a new engine of the Consolidation pattern, just received by the East Tennessee, Virginia & Georgia Railroad, we weighed a train of 30 loads, caboose and private coach, and took it with the engine to a heavy grade about a mile long, averaging 67.1 ft. per mile. The grade was not even, but undulating; some being more and some less than the average. In one place, 100 ft. were at the rate of 98 ft.; another, spots of 300 ft. at the rate of 91. and, of course, to match it other spots were less than the average. Before reaching the grade, there were about 1600 ft. of level; mostly on a 3° curve to right, which curve continued 800 ft. up the grade. Then followed [curves and tangents for 4800 ft. in all] when the summit was reached. The day was warm and dry, and circumstances favorable. The weight of train was as follows:

"Engine, 109,000 lbs.; tender, 55,000 lbs.; 32 cars, 1,453,160 lbs.; total, 1,617,160 lbs. Cylinders, 20 by 24 in.; diameter of drivers, 59 in.; weight on drivers, 97,000 lbs.

"*First Test.*—The engine stood at start at water tank about 1500 ft. from foot of grade, and when grade was reached was making about 18 miles per hour. At a point 3700 ft. from the grade the engine came to a stand, unable to take train through. It was then backed down and two cars set off, weighing 123,500 lbs., leaving weights as follows:

"Engine, 109,000 lbs.; tender, 55,000 lbs.; train, 1,329,660 lbs.; total, 1,493,660 lbs.

Second Test.—This time the engine started from the same place as before, struck the grade making 22.3 miles per hour, and in seven minutes turned the summit, making 4.5 miles per hour. The engine averaged 145 lbs. steam, was worked most of the way in the second notch from bottom, or at about an 18-inch cut-off, the last 1200 feet being in lowest notch, or what was called full stroke (22-inch cut-off). Very little sand was used; engine did not slip any.

"While this grade was undulating, it seemed fair to take the average,—which has been stated 67.1 per mile, or 1.27 per cent,—giving a resistance due gravity per ton of $.0127 \times 2000 = 25.4$ lbs.

The locomotive-power indicated by these records is then computed in the following manner—correct numerically, but wholly incorrect in its apparent indications:

	Lbs. per ton.
"Train resistance	5.0
Curve resistance on 6° curve	6.0
Grade resistance (1.27 per cent)	25.4
Total resistance to be overcome	36.4 lbs.

* *Jour. Assoc. Eng. Societies*, 1886.

"Weight of engine and train being 747 tons; 747×36.4........= **27,191 lbs.**
But about 100 ft. of the train will be on a 10° curve, where the resistance per degree is .05, or, for the 10°, .50 per cent; the estimated resistance on a 6° curve was .30 per cent: here is an excess of .20 per cent, or per ton, 4 lbs. Now, three cars are all of the train on this curve, and we have 69 tons, which gives $69 \times 4 =$ **276 lbs.**
Making a total resistance to overcome of........................ **27,467 lbs.**

"You will note that here we develop a tractive force of 28.2 per cent of the weight on drivers; not so great as in other cases, but much over ordinary practice.

"The theoretical power of the engine would be as follows: $\frac{20 \times 20 \times 24}{50}$ $\times$ cylinder pressure $= 192 \times 130$ (assumed) $= 24{,}960$ lbs.

"The estimated resistance per ton is, including the correction for the 10° curve, 36.8 lbs.

"Divide the theoretical power, 24,960, by this resistance 36.8, and we have:

$$24{,}960 \div 36.8 = 678 \text{ tons} = 1{,}356{,}000 \text{ lbs.}$$

Being the theoretical amount the engine would move up this grade, or about 137,000 lbs. less than the actual amount moved. *The actual work exceeds the theoretical by about the weight of the engine and tender.*"

949. The true explanation of this apparent anomaly is that the engine in reality did no such thing as to develop a tractive force of 27,467 lbs., nor is there any real discrepancy between the actual and theoretical work done. The true way of computing the tests is as follows:

	Per cent.
Nominal average rate of grade (that of the profile)......................	1.27
Correct for curvature at 0.03 to 0.05 vertical feet for each degree of central angle, which is in effect an addition to the grade of..............	0.12
And we have as the equivalent nominal grade, including effect of uncompensated curvature...	1.39

Where the curvature is makes no great difference, unless it stalls the train, and we need not now go into that detail.

Then to compute the first test we have:*

Train struck foot of grade at velocity of 18.0 miles per hour, and stalled in 3700 ft. Vel.-head for 18.0 miles (Table 118), 11.50 ft.; $\frac{11.50}{37.00} = 0.311$ vert. ft. per station as the work done by momentum. $1.39 - 0.311 = 1.08$ per cent as the *virtual* grade, or the one up which the ***unassisted traction of the engine*** hauled the train.

	Miles per hour.	Vel.-head.
Second Test.—Speed at foot of grade (4800 ft. long)....	22.3	17.67 ft.
" " top "	4.5	.73 ft.
		16.94

* For strict correctness the distance travelled up the grade by the centre of gravity of the train, and not the engine, should be used in this test, but as the initial velocity was taken from the engine it is impossible to do so.

$\frac{16.94 \text{ vert. ft.}}{48.00 \text{ stations}} = 0.353$ vert. ft. per station as the assistance derived from momentum, and $1.39 - 0.353 = 1.04$ per cent as the virtual grade in the second test.

All this is shown graphically in Fig. 233. At the foot of the grade the vertical head corresponding to the given velocities is erected, and

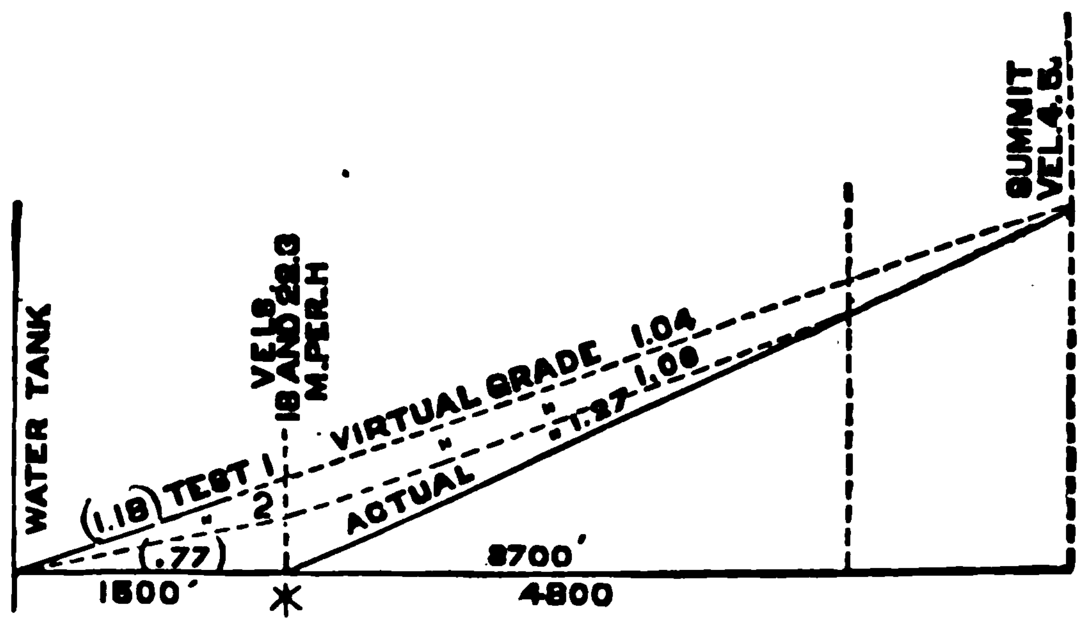


FIG. 233.

also at the head of the grade, although it is so small as to be hardly visible. The dotted lines show the virtual grades. The two tests coincide, it will be seen, almost exactly in the virtual grade which they indicate, especially if we remember that the engine used a little more steam on the upper part of the second run.

This virtual grade includes the effect of curvature, and for the power developed by the engine we have:

	Lbs. per ton.
Train resistance	5.0
Grade worked by engine power (say 1.06 per cent)	21.2
Total per ton	26.2
26.2 lbs. per ton × 747 tons	= 19,571 lbs.
Against Mr. Hudson's computation of actual work of	27,467 "
And of theoretical work with 130 lbs. pressure of	24,960 "

The actual work done requires an average effective piston pressure of $\frac{19.571}{192}$ = a fraction over 100 lbs. per square inch, which is coming down within the bounds of reason (and barely that) for a Consolidation engine carrying 140 lbs. of boiler pressure and running over 15 miles per hour.

950. We may see how these variations of velocity may tend to increase grades, and how nearly our process of computing them will check, by considering what took place between the starting-point and foot of

the grade, 1500 ft. off, over a NOMINALLY level grade. The virtual grade may be thus determined:

	In first test.	In second test.
Speed acquired in 1500 ft.	18.00	22.30
Corresponding vel.-head, ft.	11.50	17.67
Then we have, as the *virtual* grades per station..	$\frac{11.50}{15.00} = 0.77$	$\frac{17.67}{15.00} = 1.18$

In other words, in the first test the engine started off lazily and did not do as much work as after it struck the grade. In the second test the engine succeeded in doing somewhat more work than it did after it struck the grade, as is but natural from the fact that its average velocity was less and (probably) it used more sand and had a somewhat higher boiler pressure. But the correspondence is close without these allowances; quite sufficient to indicate, what is beyond question, that the method is essentially trustworthy.

Now, had this grade, instead of being only 4800 ft. long, been 48,000 ft. long, it will be evident that the same initial velocity would have done very little to help out the engine. To derive equal aid from momentum we should have needed to have a vertical head ten times as great in that case, or 176 ft., which would have carried the necessary initial speed up to the impracticable limit of nearly 71 miles per hour. Consequently, while short grades and short sags may be operated almost as levels with speeds of 30 to 50 miles per hour, long grades or bad sags can be but little helped out by momentum. In the one case the profile tells the truth, and in the other it does not.

PART IV.

LARGER ECONOMIC PROBLEMS.

"The rich man's wealth is his strong city: the destruction of the poor is their poverty."—PROVERBS x. 15.

"For whosoever hath, to him shall be given, and he shall have more abundance: but whosoever hath not, from him shall be taken away even that he hath."—MATTHEW xiii. 12.

"For which of you, intending to build a tower, sitteth not down first, and counteth the cost, whether he have sufficient to finish it? Lest haply, after he hath laid the foundation, and is not able to finish it, all that behold it begin to mock him, saying, This man began to build, and was not able to finish."—LUKE xiv. 28–30.

PART IV.

LARGER ECONOMIC PROBLEMS.

CHAPTER XXI.

TRUNK LINES AND BRANCH LINES.

951. THAT the most elementary conditions on which the success or failure of railway enterprises depend are often radically misunderstood, almost necessarily follows from the fact that the world is so full of examples of misdirected enterprise—of lines built with great hopes of profit which have proved miserable failures; while, on the other hand, there are so many examples of roads built for local purposes, or otherwise without particular expectation of a brilliant future, which have proved magnificent properties. Among innumerable examples which might be mentioned we may take the West Shore Railroad of New York as an example of the first class, and the parallel New York Central of the last: the present New York Central & Hudson River Railroad having been made up by the consolidation of six or eight different local lines, built with little or no reference to the formation of a great trunk line. These two lines are, in their different ways, striking examples of the fact that the conditions which control the future prosperity of such properties are often wholly misunderstood.

952. It seems for many reasons probable that by far the larger part of this very general misunderstanding—of the blundering into unexpected success on the one hand, and into dismal and

other failure on the other—arises from a single cause, viz., an imperfect understanding of certain elementary facts, which we will now consider, as to the effect upon the productiveness of the property of any increase in the sources of traffic. The unexpectedly good or bad fortune of hundreds of properties can be traced, in part or whole, to this single cause.

953. Let us suppose a railway to be projected, say 100 miles long, to connect two traffic points of some importance, *A B*, Fig. 233′. We will assume for simplicity that there is little or no intermediate local traffic, as often happens. We will consider *A* and *B* to be equal, not necessarily in population, but in traffic-contributing capacity to this particular line. The traffic which the railway has to support it may be then represented by the combination *AB*, being that which naturally exists between two traffic points of the importance of *A* and *B*.

Fig. 233′.

954. Let us now suppose that another alternate route may be chosen, which by a slight detour will strike an intermediate traffic point *C*, Fig. 234, of equal potential magnitude with *A* and *B*: how have we affected the revenue-earning capacity of the line?

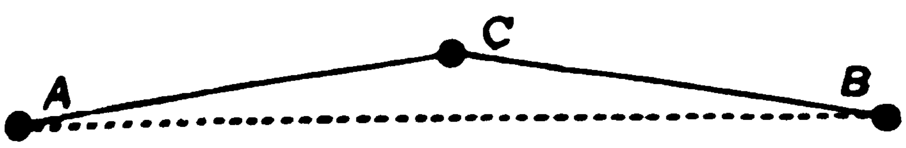


Fig. 234.

A most natural answer—beyond all question a very common answer—is that we have increased it just 50 per cent. Instead of serving perhaps 100,000 people in the two towns *A* and *B*, we now serve 150,000 people in the three towns *A*, *B*, *C*. Fifty per cent more people, fifty per cent more traffic, fifty per cent more earnings—seem natural corollaries of each other.

On the contrary, it may be shown at once that we have doubled our probable traffic, and really we have tripled our traffic, and rather more than tripled it. Instead of having only Traffic *AB*, Fig. 233′, we have Traffic *AB*, Traffic *AC*, Traffic *CB*, Fig. 234.

The value of the latter is obviously twice, and really considerably more than three times, that of the former.

To have the traffic tripled we must assume that Traffic *AB*, Traffic *AC*, and Traffic *BC*, Fig. 234, are of equal financial value —which they are, as nearly as may be.

955. An objection to this statement will naturally suggest itself—that in Fig. 234, although the traffic points *A*, *B*, *C* are equal in magnitude, yet the HAUL on the Traffic *AB* is twice that on Traffic *AC* or *CB*. Therefore, if the volume of each be the same and the rates be the same, we apparently have Traffic $AB =$ Traffic $AC +$ Traffic *CB*, so that we have only doubled instead of tripling our traffic from a revenue-producing point of view.

But these latter assumptions are not correct, either as respects the volume of or rates on traffic.

As respects the effect of distance, it may be said in a general way that, if we consider only great and decided differences of distance, the volume of traffic, both passenger and freight, will be at least inversely as the distance: that is to say, if two given traffic points, 100 miles apart, could be moved up to a distance of only 50 miles from each other, and remain otherwise unchanged, the volume of traffic between them will be at least doubled. New York and Philadelphia, for example, are 90 miles apart, and New York and Boston 231 miles. Could these cities be moved up to within 45 and 115 miles of each other the volume of traffic between them might even be quadrupled, and certainly the lines connecting them would be very much better properties, because the loss of haul would be more than made up by the increase of volume, even as respects gross revenue, leaving the saving in expenses by the shorter haul and the probable higher rates per mile almost a clear gain.

956. As to rates, it is an entirely safe general rule, that freight hauled only half as far will pay a materially larger rate per mile for the haulage proper, excluding the terminal charge, which is in effect a part of every rate.

The passenger rates per mile might well be the same or even lower, but this would only be for the reason that it was profitable to make them lower, to secure the far greater net gain from the increase of volume. The traffic would in all such cases bear a materially higher rate per mile without decreasing its volume

below what would exist with twice the haul. Taking both these considerations together, it is quite certain that, whether we consider great distances or small, nearness of traffic points is certainly no disadvantage to the financial productiveness per unit of the traffic between them. For example, if the haul on wheat to the seaboard were only half as great, it cannot be questioned that it would be a more profitable traffic, and it would possibly pay quite as large gross rates. The New York-Newark traffic, 9 miles, is far more profitable and far larger in the aggregate, in proportion to the size of the two places, than the New York-Philadelphia traffic, 90 miles. If Philadelphia were as near to New York as Newark, both the volume and the productive value of their interchanged traffic would be enormously greater than it is now

957. There are, of course, certain possible exceptions to this general rule. The tonnage between the anthracite-coal mines and New York, for example, might not be much larger than it is if the haul were only 50 miles instead of 150, for about so much must be had at any cost, and more than that is not needed. And yet it probably would be larger, both because the more favorable conditions for coal supply would have greatly stimulated manufactures, and so the growth of population as well, and because the rates per mile hauled would be higher.

958. We see, therefore, the reasons why, assuming the points A, B, C, Fig. 234, to be of inherently equal traffic-producing capacity, the short-haul traffics, AC and CB, should each one of them be of more rather than less value than the long-haul traffic, AB; from which it follows that the aggregate of the three traffics AB, AC, CB, Fig. 234, will be worth more rather than less than three times as much as the traffic AB alone.

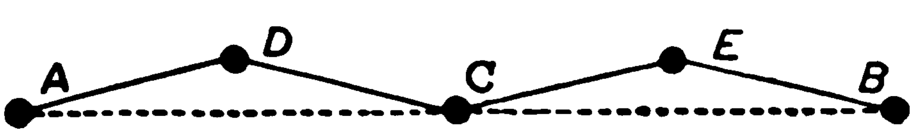


FIG. 236.

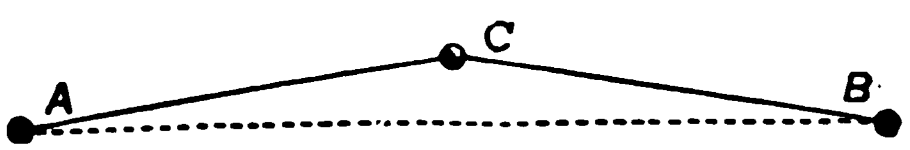


FIG. 234.

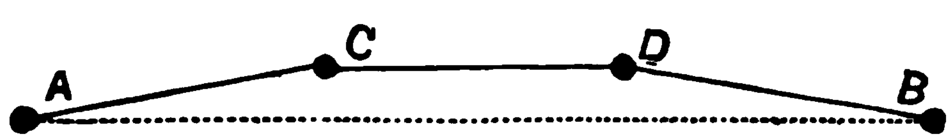


FIG. 235.

whence the ratio of increase is

$$\frac{T'}{T} = \frac{N(N-1)}{n(n-1)}. \quad \ldots \quad (4)$$

As n becomes a larger number, the ratio of n to $n - 1$ becomes more and more nearly unity, until finally the ratio of T' to T becomes sensibly

$$\frac{T'}{T} = \frac{N^2}{n^2}, \quad \ldots \quad (5)$$

which is THE EQUATION GIVING THE GENERAL LAW OF INCREASE IN EARNINGS DUE TO AN INCREASE OF TRIBUTARY TRAFFIC POINTS ON THE SAME LENGTH OF LINE; i.e., the productive traffic varies as the SQUARE of the **number of tributary sources of traffic.**

TABLE 191.

SHOWING THE EFFECT UPON AGGREGATE TRAFFIC OF INTERPOLATING ADDITIONAL TRAFFIC POINTS IN THE LINE.

[See Figs. 233–238.]

No. of Traffic Points.	Relative Traffic.	Traffic Per Unit of Population.	Per Cent Increase of Traffic by Adding One Traffic Point.	Absolute Increase of Traffic by Adding One Traffic Point.
2	1	0.5	.....	..
3	3	1.0	200.0	2
4	6	1.5	100.0	3
5	10	2.0	66.7	4
6	15	2.5	50.0	5
7	21	3.0	40.0	6
8	28	3.5	33.3	7
9	36	4.0	28.6	8
10	45	4.5	25.0	9
11	55	5.0	22.2	10
12	66	5.5	20.0	11
13	78	6.0	18.2	12
14	91	6.5	16.7	13
15	105	7.0	15.4	14
etc.	etc.	etc.	etc.	etc.

It will be seen from the last column of this table that the *absolute* gain from a given addition of tributary population is greater in proportion to the amount of other tributary population, but that the addition *per cent* is very much greater on light-traffic roads.

TABLE 192.—GROWTH OF NEW YORK CITY INTERNAL PASSENGER TRAFFIC.

YEAR.	Estimated and Actual Population.	City Passenger Traffic (Thousands).			Per Inhabitant.		
		Elevated Roads.	Horse Cars.	Total.	Elevated.	Horse.	Total.
1853......	531.	None.	(Same as next column.)	6,836	....	11.8	11.8
54......	605.	"		6,817	...	11.3	11.3
1855......	629,810	"		18,438	....	29.4	29.4
56......	663.	"		23,153	....	35.0	35.0
57......	698.	"		22,190	....	31.9	31.9
58......	734.	"		27,900	....	38.0	38.0
59......	773.	"		32,889	....	42.7	42.7
1860......	813,669	"		36,455	....	44.7	44.7
61......	826.	"		26,272	....	31.8	31.8
62......	838	"		35,878	....	42.8	42.8
63......	850.	"		40,412	....	47.6	47.6
64......	863.	"		60,900	....	70.6	70.6
1865......	876.	....		82,055	....	93.8	93.8
66......	889.	....		88,953	....	100.0	100.0
67......	902.	....		100,542	....	111.0	111.0
68......	915.	....		105,817	...	115.6	115.6
69......	929.	....		114,349	....	123.5	123.5
1870......	942,292	....		115,139	....	122.0	122.0
71......	962.	....		133,894	....	139.4	139.4
72......	982.	136	143,561	143,697	0.1	146.0	146.1
73......	1,003.	644	144,715	145,359	0.6	144.4	145.0
74......	1,024.	796	151,131	151,927	0.8	147.8	148.6
1875......	1,045,223	921	165,997	166,918	0.9	158.8	159.7
76......	1,076.	2,013	166,401	168,414	1.9	154.5	156.4
77......	1,107.	3,012	160,924	163,936	2.7	135.3	148.0
78......	1,139.	9,291	160,899	170,190	8.1	131.0	149.1
79......	1,172.	46,045	141,939	187,984	39.4	121.4	160.8
1880......	1,206,299	60,832	150,390	211,222	50.5	124.7	175.2
81......	1,249.	75,586	155,801	231,387	60.5	124.6	185.1
82......	1,294.	86,361	166,511	252,872	66.6	128.6	195.2
83......	1,340.	92,125	176,625	268,750	68.8	131.8	200.6
84......	1,387.	96,703	187,413	284,116	69.5	134.8	204.3
1885......	1,437.	103,355	193,762	297,117	71.8	134.7	206.5
86......	1,488.	115,110	206,802	321,912	77.0	148.8	215.8
87......	1,541.	158,963	203,453	362,416	103.0	132.1	235.1
88......	1,595.	171,530	199,484	371,014	107.4	124.8	232.2
89......	1,652.	179,497	206,298	385,795	108.7	125.0	233.7
1890......	1,710,715*	185,834	218,565	404,399	108.3	127.6	235.9
1891......	1,772.	201,202	229,651	430,853	113.4	129.5	242.9

* City enumeration, not U. S. census, which was shown to be too small.

Summary.

Year.	Population.	Trips per Inhabitant.			No. of Lines.		No. Trips per Inhab't per 100,000 of Population.
		Horse.	Elevated.	Total.	Horse.	Elevated.	
1853.......	581.	11.8	....	11.8	2	..	2.03
1855.......	630.	29.4	....	29.4	4	..	4.67
1860.......	814.	44.7	....	44.7	6	..	5.5
1865.......	876.	93.8	....	93.8	12	..	10.7
1870.......	942.	122.0	....	122.0	12	..	13.0
1875.......	1,045.	158.8	0.9	159.7	19	1	15.3
1880.......	1,206.	124.7	50.5	175.2	23	4	14.5
1885.......	1,437.	134.7	71.8	206.5	....	....	14.4
1890.......	1,711.	127.6	108.3	235.9	....	....	13.8

Since 1885 a further and great increase has begun, so that there is every prospect that it will be more notable in proportion than heretofore.

While the growth of city travel is in some respects a special problem, since its increase results in great part from the increasing distances which larger population brings, yet it is mainly but one expression of a general law brought out in Chap. XXI., that traffic tends to increase about as the *square* of the population or sources of traffic united by convenient means of communication. Quite as forcible an illustration of this law is obtained by studying the growth of traffic of States and the United States as elsewhere presented. Compare Tables 14, 15, 16; also Tables 2, 3, 7, 21 to 28, 34, etc.

960. It is plain that we cannot always, nor ordinarily, count on any series of points *A*, *B*, *C*, *D*, *E*, etc., each of which is exactly equal to each other, but we may push the generalization a little farther.

Taking the entire population of a country, or of a continent, or of the world, and conceiving it to be made up of a great number of units, either of single individuals or of groups of 10, 100, 1,000, or 1,000,000 individuals, it is plain that each one of these units has potential traffic relations with every other unit. The components of each unit visit those of the other socially; they buy and sell from each other; they visit each other in the hope of buying and selling; they produce more (this is an invariable law) for the especial purpose of supplying the necessities of others with whom they have or finally secure traffic relations. Until such traffic facilities exist, these relations are inchoate, or merely potential. As the facilities are extended they become actual;

and they should tend to become actual, if our reasoning has been correct, about in proportion to the SQUARE of the facilities afforded and of the population served. Experience seems to show that they do tend to increase about in this ratio, some evidence of which fact is contained in Table 192, as also in Table 14, 15, 16, and others referred to below Table 192: but however this may be, that they increase in very much more than direct ratio is beyond all question.

It is therefore unnecessary to take each individual town as a traffic unit, as we have done heretofore. We may regard each individual person as the traffic unit, and while it will be by no means literally true that he will have actual traffic relations with all those for whom the facilities exist, but only with every tenth, hundredth, thousandth, or millionth person, according to his character and occupation, yet practically the result is the same. His aggregate contributions to railway traffic will vary in close accordance with the total population connected with him by traffic facilities, and his payments to any particular line will be in direct proportion to that fraction of the total of the whole population connected with him by traffic facilities which is reached by him over that particular line.

961. We have thus only to consider the points A, B, C, D, E, Figs. 233–237, to represent single individuals instead of towns or other traffic points, and to consider their number n to be indefinitely multiplied, when precisely the same process of reasoning we have just applied to towns leads to precisely the same conclusion as respects individuals.

We then have $n(n-1) = n^2$ [Eqs. (4) and (5)] almost exactly; whence, if P = the actual tributary population on the line and p = a possible additional population, the percentage of increase in traffic L, all other things being equal, will be,

$$L = \frac{(P+p)^2}{P^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In other words, if we have 1,000,000 tributary population and

can add 100,000 more, each unit of which is of the same traffic-producing capacity, the increase will be

$$\frac{(10 + 1)^2}{10^2} - 1 = 21 \text{ per cent.}$$

If our original population were 500,000, we should have, all other things being equal,

$$\frac{(5 + 1)^2}{5^2} - 1 = 44 \text{ per cent.}$$

This is really a more correct way of arriving at the theoretical effect of additional sources of traffic than that used in Table 191, since it takes each individual as the unit, instead of a group of 20,000 or 100,000. It gives a somewhat smaller percentage, but the difference is not great enough to make a material difference in what are at best merely illustrative computations; not susceptible, nor supposed to be susceptible, of exact application in practice, except as indicating the COMPARATIVE probable revenue, all other things being equal, of alternate routes between the same termini.

962. In any actual instance, of course, all other things would be more or less unequal, and hardly any of them equal, so that it would be quite impossible to make any very precise estimates by the formula given. In the first place, it is impossible to more than guess at the true tributary population. That which is apparently tributary, from being on the line, is decreased by the competition of other lines, so that only a fraction of it is really tributary; while, on the other hand, there may be an immense population beyond the limits of the line itself which is indirectly tributary to it through the medium of other lines, as in the case of the trunk lines from the sea-coast to the west. In the second place, a mere enumeration of heads is a very rude index of the traffic value of those heads. A great mining or manufacturing or commercial point will contribute vastly more traffic per head than other more inert communities, and a large town, almost always, more per head than a small town.

963. Nevertheless, when we connect Smithville with our line we get the New York-Smithville as well as the Smithville-New York traffic; and the traffic of New York is made up only of the aggregate of that to thousands of Smithvilles, of which we get those which we reach in one way or another by our line. Thus the discrepancy on account of the difference in the traffic-producing capacity of individuals is less than might be supposed, and Tables 14, 15, 16, and 191, with various others in this volume, show that the law holds tolerably well when applied on a large enough scale to eliminate sources of irregularity, while there are innumerable examples of single lines whose prosperity or adversity can be directly shown to imply the existence of some such law.

These fundamental truths being granted, therefore, it leads very directly to certain conclusions as to the proper manner of laying out both trunk lines and branch lines; conclusions which, while they may be difficult to apply so exactly as to avoid a considerable percentage of error, will yet be so definite that the radical error of mistaking black for white, so to speak—taking that for the best course which is rather the worst course,—is not likely to occur.

TRUNK LINES.

964. Trunk or main lines may be roughly divided into two classes: those which are, and those which are not, liable to be subjected to close competition at almost every important point.

Almost all lines in the United States belong to the former class. Their only permanent protection against competition, in most cases, is to throw out a skirmish-line of branches and parallel routes so as to cover securely a considerable territory; and this is one great reason for the tendency in that direction which is so notable, and which has already gone so far that more than half the mileage of the United States is controlled by a dozen managements, with every prospect that the tendency to consolidation will grow still stronger. Table 193 shows how far this tendency has already gone. Another and still stronger reason, however, directly results from what has preceded—that every

Table 193.

Length of Road and Gross Earnings of Fourteen Great Systems of Road in the United States, 1881.

[Abstracted from a Paper by Wm. P. Shinn on "Increased Efficiency of Railways for the Transportation of Freight," Trans. Am. Soc. C. E., November, 1882, with the addition of the Baltimore & Ohio, Atchison, Topeka & Santa Fé, and some minor details.]

	Miles.		Gross Earnings.	
New York Central & Hudson River	993		$29,322,532	
Lake Shore & Michigan Southern	1,177		17,880,000	
Canada Southern	403		3,369,259	
Michigan Central	950		8,800,486	
Total New York Central System		3,523		$59,372,277
New York, Lake Erie & Western		1,020		20,715,605
Pennsylvania, Eastern System	3,041		$44,224,716	
" Western "	2,529		31,058,790	
Total Pennsylvania		5,570		75,283,506
Baltimore & Ohio, Eastern System	595		....	
" " Western "	959		....	
Total Baltimore & Ohio		1,554		18,463,877
Total Four Trunk Lines		11,667		$173,835,265 Per Mile $14,900
Per cent of total United States		12.35 p. c.		23.97 p. c.
Wabash, St. Louis & Pacific		3,348		$14,467,790
Chicago, Burlington & Quincy		3,160		21,176,455
Chicago, Rock Island & Pacific		1,335		11,956,907
Illinois Central, Northern	1,320			
New Orleans line	571			
		1,891		10,793,105
Chicago & North-Western		3,276		19,334,072
Chicago, Milwaukee & St. Paul		4,260		17,025,461
Missouri Pacific, Main System	1,012		$8,640,957	
Leased and controlled lines	4,773		19,087,484	
		5,785		27,728,441
Louisville & Nashville, Owned	1,438		$10,911,650	
Leased lines	434			
Louisville, Cincinnati & Lexington	272*		1,196,112	
Nashville, Chattanooga & St. Louis	521		2,256,186	
Georgia Railroad System	641		2,543,032	
		3,034		16,906,980
Atchison, Topeka & Santa Fé		2,240		12,584,509
Union Pacific, Proper	1,821		$24,258,817	
Lines in interest	2,449		7,608,936	
		4,270		31,867,753
Central Pacific	2,874		$24,094,101	
Southern Pacific	1,281		3,435,945	
		4,155		27,530,046
Total Ten Systems other than N. Y. Trunk Lines.		36,754		$211,371,519 Per Mile $5,751
Per cent of total United States		38.90 p. c.		29.14 p. c.

* This line is not included in the totals.

TABLE 193.—*Continued.*

	Miles.	Gross Earnings.
TOTAL FOURTEEN GREAT SYSTEMS.................	48,421	$385,206,784 Per Mile $7,956
Per cent of total United States..................	51.25 p. c.	53.11 p. c.
TOTAL OF MINOR LINES of the United States, under 300 to 400 different managements....	46,065	$340,118,335 Per Mile $7,383
Per cent of total United States..................	48.75 p. c.	46.89 p. c.
Total of the United States in 1881, of which earnings were reported...........................	94,486	$725,325,119 Per Mile $7,677

Since 1881 there have been many changes in the details of the above table, but the great systems given probably cover in the aggregate a still larger proportion of the total mileage of the United States. There were in 1881 a total of 104,813 miles reported built, 10,327 miles of which did not report earnings, being largely newly built lines.

addition to the tributary population makes the revenue per head from the previously tributary population greater. This may not often, perhaps never, be more than dimly felt, but that it is the true cause and justification for many such extensions we cannot doubt.

Nevertheless there are certain mountainous or sparsely populated and poor regions, in this and all other countries, where reasonable freedom from competitive lines is assured, as in Mexico, the lines in which afforded some instructive examples of the right and wrong way of laying out main lines.

965. Bearing in mind what we have already seen as to the small expense of operating extra distance (par. 197), the appreciable additions to revenue which may be expected to arise from it (par. 230), and the small effect of moderate additions of distance to discourage traffic, there can be no question that the fundamental rule for laying out such lines—deviated from only for good special reasons—should be to link together the largest possible population, regardless of minor losses of distance, provided THE AGGREGATE POPULATION PER MILE OF ROAD is not diminished (par. 237), or even sometimes if it is. An ultimate

limit, beyond which it would certainly be unwise to go, and hence which should not be closely approached, is that the increase per cent of distance should not exceed the increase per cent of probable revenue, according to eq. (6), par. 961.

966. The most marked exception to this rule is when the difference of distance becomes so great as to seriously discourage traffic, or encourage the construction of a more favorably situated competing line.

A further exception is when, by passing midway between two traffic centres, neither of which can be reached readily by the main line, both may be served fairly well by branches or otherwise (par. 66).

Any marked difference in grades or costs of construction may of course make a difference either *pro* or *con*; but entire disregard of the rule, by deliberately neglecting intermediate traffic points for the sake of through traffic, usually means financial failure.

967. Several instances of the application of these general rules may be studied on any map of Mexico, showing the existing railway lines. The most pronounced is the choice between the route from the City of Mexico to the United States (*via* the Mexican Central or the Mexican National routes), either of which could be chosen by the Central at the time the concessions were granted.

The longer line, passing through the heart of Mexico, and thence connecting at El Paso with the Atchison, Topeka & Santa Fé, was chosen. The grounds for this choice, beyond question, were that (1) railways in Mexico were to be profitable; (2) the more railway controlled the more aggregate profit, even if the less per mile; (3) a long line through the heart of a country must in the long-run be the best line.

On the other hand, the choice violated two of the fundamental rules which have been laid down. First, it seriously discouraged traffic between Mexico and the United States by burdening that which passed over it with nearly 500 miles of extra haul: this practically insuring that the National line, when completed, would be, or might easily make itself, the leading through line. Secondly, it very materially decreased the average tributary population per mile over what it would have been had the Mexican Central line been followed as far as Celaya, in Central Mexico, and the Mexican National from there north; especially had the

towns of Silao, Guanajuato, and Leon been linked to this main line by a branch, as they might have been later.

Had the Mexican Central been built by this line there can be little doubt that it would be to-day (1886) a most flourishing property, both because its investment would have been smaller and its traffic larger.

968. On the other hand, leaving the flourishing town of Durango on one side, although it saved distance in what was already a disastrously long line, was probably an error, although this cannot be asserted with much positiveness. The loss of perhaps 50 or 60 miles more would have taken the line through a much better country, actual and prospective, for nearly 400 miles, the country through which the line was actually run having been almost the poorest possible; while saving that loss of distance did not materially improve its already bad case as respects through traffic.

969. The National, for its part, fell into an error which has often been committed before, and never without loss—attempting to start a new terminal port at Corpus Christi, instead of making for Galveston direct. Such projects for changing the established course of trade seem to have a peculiar fascination for sanguine projectors, but it is always all but certain that they will end in failure.

The more instructive example to be found on the National lines, however is a striking instance of how, when traffic is at best thin and probably non-competitive, connecting the largest possible population by the main line is almost surely the wiser course. Fig. 239 shows this instance, the dotted line being what had been projected, and the full line the route finally chosen by the company on the writer's recommendation.

The full line seems a most roundabout course for a main line, especially as the total mileage to be constructed was not diminished, but rather increased. It was to be remembered, however, first, that the traffic was thin and non-competitive; secondly, that the number of trains could not be great; thirdly, that reasonably good facilities for continuous traffic between every one of the many points connected by the line was desirable; and, finally, that with a traffic thin at best the maintenance and separate operation of branch lines is very burdensome. It was therefore decided, as respects the line from Morelia to Zamora and La Piedad, that it would be better to make the branch to Pátzcuaro a part of the main line, thus accomplishing the double end of decreasing the aggregate mileage to be operated and maintained, and facilitating Pátzcuaro-Zamora traffic and (by more trains) Pátzcuaro-Morelia traffic, while gaining more revenue from through traffic by not materially heavier through rates.

970. Beyond La Barca, although the line had already been run out of its course from Pátzcuaro to the Pacific, it was decided to run it still farther north to take in the important city of Guadalajara, the second city in Mexico (about 80,000 inhabitants), whence the line started almost due south for Colima and the coasts. This change alone much more than doubled the probable traffic per mile of the road, and it would have been, from an economic point of view, a very great error not to do it.

FIG. 239.

It in effect cut the line into two—one from Guadalajara to the coast, and one from Guadalajara to Mexico; but all the more it was desirable. The sharply accentuated topographical conditions, which it is impossible to describe with more detail, made this particularly clear.

971. TRUNK LINES OPEN TO DESTRUCTIVE COMPETITION, and able to command only a narrow belt on each side of them as their natural tributary territory, nor that, unless they afford almost as good accommodations as it is possible to give, can of course

afford no such sacrifice as this. As the subject is a large and complex one, the conditions of success and failure may perhaps be more usefully indicated in a small space by a few notes from the history of the actual trunk lines, and notably of the four trunk lines *par excellence*—the New York Central & Hudson River, Erie, Pennsylvania, and Baltimore & Ohio—than by a more general discussion.

972. The New York Central is probably the most striking example in the whole world of two truths: That lines connecting the largest aggregate of population will be likely to lie on the most favorable route for easy grades, and that easy grades give an overwhelming advantage in handling low-rate traffic especially. As a through line the New York Central was not made,—it grew. Some fifteen different corporations built its New York-Chicago line, each without a thought of doing more than connecting its own particular termini. Consequently it did connect them effectually, and the magnificent string of towns from which the New York Central has drawn its chief prosperity was the result.

Its intended rival, the West Shore, was built in a very different way. It was—unfortunately—planned. From attaching exaggerated importance to through traffic and to the effect thereon of accommodating way traffic, or from other cause, several of the most important local points, as notably Albany and Rochester, were left at one side, and others ill served, there being hardly a competitive point on the line, not even its two termini, as well served by it as by the Central. This may have been unavoidable. The expense alone of doing otherwise would have been enormous, and had the expense been incurred it might not have insured the success of the line; but the fact that it was not, foredoomed failure—for the two reasons, that the line which is only half as convenient as another does not, therefore, get half as much business, but none at all (par. 51 *et al.*); and for the further reason (par. 959), that the value of a line is as the SQUARE of the population best served by it.

973. From the through business proper the New York Central has derived comparatively little benefit. Its greater length reduces its average receipts per mile on competitive traffic materially below those of the Pennsylvania, and the magnificent water-way which is immediately adjacent to it for the entire distance from New York to Chicago has tended powerfully to still further curtail its rates. But its unequalled grades (by much the most favorable in the world for a line of such length), and the

indirect benefit of its immense local traffic, which alone required and supported all the staff and plant of a great railway, enabled its through business, vast as it was, to be handled as so much extra business, the only expense for which was the direct outlay for wages and fuel and a small amount for wear and tear of track.

Of no other trunk line was this so nearly true, but the lower rate per mile, and high cost for fuel and (comparatively) raw material on the New York Central, has united to produce one result which is not always understood: The per cent of operating expenses to receipts is and has always been high on it, as shown more clearly in Table 37, page 110, viz.:

	Average 1876–80.	Average 1881–85.
New York Central,	61.3	67.9
Erie,	70.0	69.7
Pennsylvania,	55.7	58.3
Baltimore & Ohio,	53.9	56.0

This contrast is immutably fixed by the nature of the traffic and the operating conditions, and gives no indication of relative efficiency of operation, as has often been carelessly assumed.

974. The increase in the percentage of operating expenses which is visible above in the figures for every one of the three lines but the Erie, is due simply to the enormous reduction in rates in recent years, the latter being at once a cause and effect of the still more enormous increase in volume of traffic. The astounding and almost incredible figures for this change are shown in Table 194, and graphically in Fig. 240. The history of the world affords no parallel to it, and it is one of the strongest proofs that we have not erred far in our conclusions in the first part of this chapter.

975. THE PENNSYLVANIA is in many respects a contrast to the New York Central. Like the latter, it grew, rather than was made, as a New York and continental trunk line. Projected to bring traffic from the West to Philadelphia only, it chanced to lie in the most favorable position for a short low-grade line between New York and the West. The irresistible tendency of events, and of its situation, linked with it a Pennsylvania-New York line on the East, and a branching network of lines through the West. In comparing it with the New York Central one is immediately struck by the contrast in this respect which its policy affords, and while much of this may well be due, and no doubt is, to a difference in the "personal equation" of the managers, an underlying reason for it—of which, perhaps, no one was conscious—is that the Pennsyl-

Table 194.

Increase of Traffic and Decrease in Rates on Various Groups of American Lines, 1865–1885.

[The last part of this table is shown graphically in Fig. 240.]

Year.	Seven Trunk Lines.		Six Chicago Roads.		Twenty-one Leading Lines.			
	Ton-miles. (1 = 1,000,000.)	Rate. Cents.	Ton-miles. (1 = 1,000,000.)	Rate. Cents.	1 = 1,000,000. Tons.	1 = 1,000,000. Ton-miles.	Freight Earnings. (1 = $1000.)	Rate. Cents.
1865 ...	1,654	2.900	513	3.642	22	2,370	$69,825	2.945
1866....	2,044	2.546	577	3.459	28	2,981	77,003	2.582
1867 ...	2,258	2.306	768	3.175	30	3,222	75,381	2.338
1868....	2,651	1.951	893	3.154	35	3,743	80,141	2.140
1869....	3,159	1.715	1,054	3.026	39	4,408	87,426	1.983
1870 ...	3,744	1.585	1,234	2.423	39	5,111	88,488	1.731
1871....	4,341	1.478	1,233	2.509	50	5,937	97,186	1.636
1872....	5,181	1.475	1,337	2.582	59	6,972	112,408	1.612
1873....	5,782	1.470	1,749	2.188	67	7,885	127,045	1.611
1874....	5,879	1.342	1,851	2.160	65	8,020	108,598	1.354
1875 ...	5,937	1.161	1,904	1.979	63	8,380	107,657	1.284
1876....	6,739	.983	1,994	1.877	69	9,072	102,009	1.124
1877....	6,536	.971	2,211	1.664	73	9,131	100,804	1.103
1878....	8,853	.807	2,822	1.476	75	10,433	105,973	1.015
1879....	10,120	.725	3,470	1.280	96	13,033	114,255	0.876
1880 ...	10,544	.840	4,544	1.266	106	14,085	139,331	0.988
1881....	11,659	.759	4,435	1.420	126	16,074	146,699	0.912
1882....	11,189	.665	5,041	1.364	134	16,075	147,719	0.918
1883....	11,141	.842	5,768	1.308	142	17,307	167,564	0.968
1884 ..	10,719	.740	5,940	1.251	144	17,501	153,735	0.878
1885 ...	11,331	.636	6,287	1.200	151	18,837	144,562	0.767

This table is from data compiled by Mr. Henry V. Poor. The seven trunk lines are the Pennsylvania; Pittsburg, Fort Wayne & Chicago; New York Central; Lake Shore; Michigan Central; Boston & Albany; and New York, Lake Erie & Western. The six Chicago lines are the Illinois Central; Chicago & Alton; Chicago & Rock Island; Chicago, Burlington & Quincy; Chicago & Northwestern; Chicago, Milwaukee & St. Paul.

These thirteen roads, with eight others of most prominence, are included in the last part of the table, from which Fig. 240 was constructed.

vania had more to gain by extending itself in all directions, and more to lose by not doing so. ADDITIONAL traffic we have seen (par. 41) to be that on which railways grow rich. With the greatest city of the country only ninety miles off, it was indispensable, to secure the utmost traffic from it, to reach it by its own lines, even with a friendly independent connection as an alternative. The futility of terminating a line at any

other than the largest available city was never better illustrated, unless by the experience of the Erie at Dunkirk on a smaller scale. Perhaps

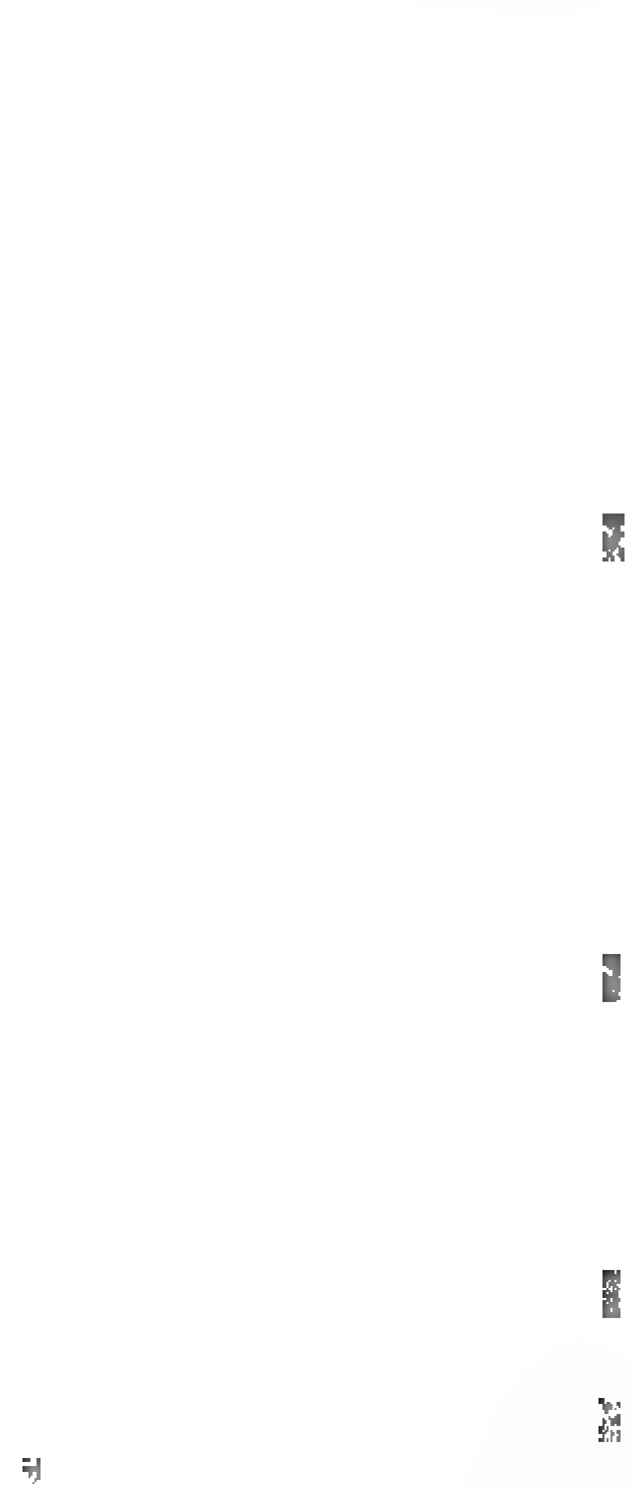


FIG. 240.—DIAGRAM SHOWING THE REDUCTION OF RATES AND INCREASE IN ON TWENTY-ONE LEADING LINKS OF THE UNITED STATES. (Shown more

Fig. 241 is as good an object-lesson as could be found as to the folly of such attempts, even when circumstances seem to especially favor what sanguine projectors look on as a "fair divide" of an enormous traffic.

976. A larger reason, which includes the first, was that the Pennsylvania was so situated as to form a very short line between almost all points on the West and the sea-coast. This insured good average rates per mile, while the abundance of coal and iron on the line, and the large amount of favorable grades insured low operating expenses. The Pennsylvania had much to gain, therefore, from handling additional through traffic OVER ITS OWN LINES, according to the law laid down in par. 211—that the only conditions under which a line could reap the full benefit of being a short line was that it should reach all its important traffic points by its own lines. The Pennsylvania was such a short line; it proceeded to satisfy the other half of the true, and too little considered, conditions of prosperity, as it was its natural policy to do. Until it did so it was, by its existence and facilities, making the fortunes of other lines instead of its own.

FIG. 241.—NORTHWESTERN GRAIN RECEIPTS AT VARIOUS LEADING SHIPPING POINTS, 1876–1885.

[One of many illustrations of the persistency with which traffic flows to leading and well-established centres, as compared with the irregularity and uncertainty of traffic at minor points.]

Moreover, the additional through traffic, which it could secure by controlling its connections, was a great object to it, for it made, and must always continue to make, a comparatively large profit on it, while

to the New York Central it was a small object, because it made a small profit out of it. The New York Central's chief reliance has been on its local traffic; its through rates per mile being necessarily low at best, even on that traffic so situated as to come to it most naturally, while its expenses were higher because of dear fuel. Had it gone much out of its way to seek more through traffic, its average rates per mile would have been lower yet, and unremunerative. Therefore it has not done so.

977. In part, this likewise explains why the unfortunate ERIE has never tended to ramify throughout the West; but the Erie is an example of a line which has succeeded in spite of this disadvantage, for four reasons:

1. By terminating at the greatest city of the East, and (after correcting the error of attempting to make a new great city at Dunkirk) at the chief traffic point at the eastern end of the great lakes, making two admirable termini.

2. By its skilful location, most of its line being on very low grades indeed, although it has some high summits and bad sections.

3. By its local coal traffic and cheap supply of fuel.

4. By its large and growing local traffic—less than the New York Central's, but larger than the Pennsylvania's, and until very recently little subject to competition.

These gave it great powers of offence against the New York Central, and it has been able to command at all times a fair proportion of the traffic which lines in the Central interest brought to Buffalo. But the Erie's prosperity has been injured by three causes quite as potent:

1. Of all the great Eastern cities, the Erie reached advantageously only ONE, whereas the New York Central reached TWO, New York and Boston (in fact, all New England and a large part of the Canada trade has been almost monopolized by the Central), and the Pennsylvania reached FOUR; the two greatest directly, New York and Philadelphia, and Boston, Baltimore, and Washington fairly well. This has been the primary difficulty with the Erie. "To him that hath shall be given." It might pay the Pennsylvania well to control a line to Smithville in order to secure thereby its traffic with the whole Atlantic coast, when it would not pay the Erie at all to own a line to it which would secure only its New York business. "Whosoever hath not, from him shall be taken away even that he hath."

The Smithville-Pittsburg traffic, the Smithville-Boston traffic, and the Smithville-Jonesburg traffic naturally gravitated to the line which commanded its other traffic East; and so the owners of lines in the West were naturally drawn most to that line which offered the most widely

ramifying connections, and could both give and ask better terms. Hence it has happened—

2. The Erie has never been able to secure good Western connections. The only serious attempt in that line, until 1881, was the old Atlantic & Great Western, one of the most ill-judged enterprises which has ever been constructed in this country, whose failure was foredoomed from the beginning, as pointed out in par. 215 *et seq.* We may be tolerably assured that the Erie never will have a great system of connecting lines, for it is not planned to secure them. In this respect the history of the road is full of instruction.

3. The Erie has been peculiarly unfortunate in its past management—in part from lack of comprehension by its foreign owners of its necessities and conditions.

978. THE BALTIMORE & OHIO is somewhat of a contrary example—of a line whose judicious and consistent management has given great financial strength to a property under many disadvantages. It has obeyed the irresistible tendency of the times by extending its lines to Chicago in the West (as well as to the Ohio River tier of cities) and to Philadelphia and New York on the East. The effect of the latter it is as yet (1886) impossible to foresee; but unless the laws of railway prosperity which prevail elsewhere are to fail in its case, it will result in a very great addition to its traffic, giving it what it has never had before—what may be called a continental traffic.

For the Baltimore & Ohio, as it stood up to about 1880, was merely an example of the financial strength which may be secured by locating between considerable local sources of natural traffic, and holding strictly to them. Between Baltimore and Washington on the East and Pittsburg, Cincinnati, Louisville, and St. Louis on the West, the Baltimore & Ohio was the natural channel of communication, and as good a one as could be secured. A large coal traffic was also assured to it. On this it prospered, avoiding dissipation of its means on many branches and connections. Nevertheless, it was economically impossible that it should fail for long to reach out to the other large cities mentioned, and to transfer itself from a local line to a national one.

Had the Pennsylvania chosen to restrict itself to its main line between Pittsburg and Philadelphia, with a few only of the most necessary branches, it also would have been, and might have indefinitely continued to be, a prosperous local line of the kind that the Baltimore & Ohio was. It might even have earned as good or better dividends than now, but its cost and value, and its earning capacity likewise, would have been far

less, and its aggregate profits vastly less. It was therefore not to be expected, nor for the public interest, that it should pursue this policy.

979. In the history of these four trunk lines, could we afford space to consider it in detail, we have warning of almost every possible danger which can arise in the laying out of trunk lines —meaning by the latter term not necessarily lines of enormous traffic (see par. 981), but lines the main part of whose traffic is complete in itself, so that they are not mere branches or feeders of other lines. We may summarize a few of the more important conditions of success in such lines as follows:

1. They must reach by their own lines the largest traffic point at each end which is at all within reach by an extension of 20 or 30 per cent of their length, and there must stand on equal terms with their connections as respects benefits and injuries to be given and received. Failing to do this is pretty sure to result in great loss, and generally in insolvency.

2. They must reach without fail every considerable intermediate traffic point along their line which can be reached by any reasonable detour or even sacrifice of grades, their prosperity being about as the square of the tributary population.

3. They can in no case attempt to create new channels of trade, as by attempting to make a seaport out of some neglected roadstead, without the greatest risk of failure. The attempts in this direction have been many; the successes as yet NONE.

4. Nearly or quite half of their traffic must practically begin and end on their own lines, either because it goes no farther, or because it is delivered at some great competitive distributing point.

5. It is of little avail to run a line even from a great city to nowhere. The apex to the pyramid in Fig. 238 is eloquent and truthful in this respect. Without a good traffic-point at each end of a line the conditions for great prosperity are not present.

BRANCH LINES.

980. That branches are in the main profitable investments is evident from their very rapid rate of increase, which is largest,

towns of Silao, Guanajuato, and Leon been linked to this main line by a branch, as they might have been later.

Had the Mexican Central been built by this line there can be little doubt that it would be to-day (1886) a most flourishing property, both because its investment would have been smaller and its traffic larger.

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last, in rolling-stock, in alignment—are still more striking, proving almost to demonstration that the law (to which there are of course exceptions) is that distinctively light railways do not prosper, or if they prosper, do not stay light. We need not search far to find some strong reasons why this should be so, and it is well that every one should do so who is concerned in projecting a light line before finally deciding on its details of construction; not because so doing will necessarily induce him to abandon his intention,—very light lines are often justifiably built, and are the only alternative to none at all,—but because it is always desirable that the consequences of an intended course of action should be fully understood in advance.

990. The first and greatest question in connection with a light railway is, What weight of rails shall be chosen? This is so for two reasons: First, because the rail is the largest single item of expense on such a line, and secondly, because on the weight of rail hinges the character of the rolling-stock, the ties, the ballast, and so to a greater or less extent almost every other detail of the line. The rail question is therefore a very fundamental one, which we may well consider with some care.

Cutting down the rail section is almost the first point of attack for a certain large class of economists, much as cutting ten per cent off salaries is liable to be at a later period in the history of a railway. There is probably no other way in which anything like as large a saving can be effected with so little demand upon the time or thought or skill of the manager; nor does it admit of doubt that either or both of these economies may at times be both expedient and necessary. Nevertheless, they would not, we may be certain, be resorted to nearly so often as they are if the full extent of the sacrifice made were realized.

991. That it is not more fully realized as to rails is probably due in the main to a not unnatural impression that in buying rails what one wants is STEEL: That if light and heavy sections are the same price per ton, buying a 30-lb. section instead of a 60-lb. is like a poor and hungry man buying a one-pound loaf at five cents instead of a two-pound loaf at ten cents.

This is not at all the case. In buying rails we are not buying steel; at least we do not care to buy it. We are buying three imponderable qualities: (1) STIFFNESS, (2) STRENGTH, (3) DURABILITY. If we get our money's worth of these qualities, it is a matter of complete indifference (except the future scrap value of the steel, which a poor, light traffic road cannot afford to give much thought to) whether we get much or little of steel. If we do not get our money's worth *of what we want*, our bargain is just as bad, however much steel we get.

992. To determine whether we do or not, one must, unfortunately, use an intelligence somewhat higher than that of a hay-scale. Any absolute measure of the qualities mentioned is especially difficult. Thus, it may be hardly necessary to say here that to estimate exactly our stiffness and strength we must determine the position in the rail section, Fig. 245, of two little points which lie at a distance called the RADIUS OF GYRATION from the centre of the rail (meaning simply the points where, if all the steel in base and head were concentrated, it would have the same power to resist gyration, i.e., bending, as it now has) and we must then make a number of other assumptions in regard to the character of the load and support which we well know are not only doubtful, but will not be even approximately true in practice, unless by accident.

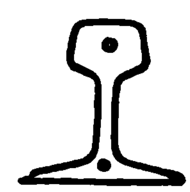
FIG. 245.

But for comparative purposes all this is unnecessary. The support given to the rail from below by the road-bed and ties may be assumed the same for any section of rail, whatever it may be absolutely. We may assume that any two or more sections requiring to be compared will be practically "similar" to each other, i.e., with the same proportion of base to height, etc. etc., so that Fig. 245 may, by simply varying the scale, be taken to represent a section of any weight from 10 to 100 lbs. per yard, and yet be tolerably well designed even for these extremes.* From established mathematical laws we also know that the

* It is badly designed in having a head flaring outward at the bottom, but that is a detail we need not enter into.

weight will, under these assumptions, vary as ***breadth* × *height*,** and that the stiffness will vary as ***breadth* × *cube of height*.** That is to say, if we multiply every dimension by two, we increase the weight of the section by $2 \times 2 = 4$, but the stiffness by 2×2^3 or $2 \times 8 = 16$ or 2^4; in other words, the stiffness in that case varies as the fourth power of the increase in linear dimensions, whereas the weight varies only as the square.

993. An algebraic demonstration of the simplest character, which it is unnecessary to give here, would prove this result to be in accordance with a general law—that THE STIFFNESS IN A RAIL VARIES AS THE SQUARE OF ITS WEIGHT PER YARD. If we increase the weight

10 per cent,	20 per cent,	30 per cent,

we shall increase the stiffness to

$1.10^2 = 1.21$,	$1.20^2 = 1.44$,	$1.30^2 = 1.69$,
or 21 per cent,	or 44 per cent,	or 69 per cent.

Mere formulæ have a hazy, indefinite sound, which, it is evident from what we see around us (for these general facts are well enough known), do not produce much impression on the mind; but let us reduce them, in the accompanying Table 195, to the plain, practical basis of HOW MUCH STIFFNESS WE GET FOR A DOLLAR with light and heavy rails, and we shall have some more forcible, because more readily comprehensible, evidence as to why light rails are sooner or later avoided as the plague by all railways; admitting the evident fact, that for light lines especially stiffness is not only by much the most important quality a rail can have, but (as we shall see more fully) by much the cheapest stability to be had in the market—far cheaper than tamping-bar stability, which roads of heavier traffic can afford to rely on more extensively. In Table 195 a 50-lb. rail is taken as the unit of comparison, as being about the maximum for distinctively light railways and the minimum for those of ordinary type, and the cost of rails is taken at the even figure of $30 per ton.

TABLE 195.

COMPARATIVE AMOUNT AND COST OF STIFFNESS IN LIGHT AND HEAVY RAILS.

Weight of Rails. Lbs. Per Yard.	Tons Per Mile.	Cost Per Mile at $30 Per Ton.	Comparative Stiffness.	Cost Per Unit of Stiffness.	Comparative Value Received for $1.
10	16	$480	.04	$12,000	20 cts.
15	24	720	.09	8,000	30 cts.
20	32	960	.16	6,000	40 cts.
25	40	1,200	.25	4,800	50 cts.
30	48	1,440	.36	4,000	60 cts.
35	56	1,680	.49	3,429	70 cts.
40	64	1,920	.64	3,000	80 cts.
45	72	2,160	.81	2,667	90 cts.
50	**80**	**2,400**	**1.00**	**2,400**	**$1.00**
55	88	2,640	1.21	2,182	1.10
60	96	2,880	1.44	2,000	1.20
65	104	3,120	1.69	1,846	1.30
70	112	3,360	1.96	1,714	1.40
75	120	3,600	2.25	1,600	1.50
80	128	3,840	2.56	1,500	1.60

Tons of rail per mile taken at 1.6 tons per lb. per yard, allowing for a certain minimum of side track. Main track only requires $\frac{11}{7}$ or 1.571 tons per pound per yard.

Comparative stiffness (4th column) is as the square of the weight per yard, 50 lbs. being taken as the limit of comparison. *Cost per unit of stiffness* (5th column) is given by dividing column 3 by column 4. *Comparative value received for* $1 (last column) is given by dividing $2400 by column 5.

994. This table should be carefully studied. It will be seen from it that the lighter the original section of a railroad, the more it loses by using a light section, because the more would be its proportionate gain from a given increase in weight of section. The sacrifice of value in buying light sections is precisely the same as if in buying rails we were, in fact as well as in form, buying STEEL instead of STIFFNESS, and were to choose light sections in spite of the following market quotations:

	Per ton.
Steel in 20-lb. sections,	$75 00
" 30 " "	50 00
" 40 " "	37 50
" 50 " "	30 00
" 60 " "	25 00
" 70 " "	21 43
" 80 " "	18 75

Or, again, our loss is the same as if we were offered a certain amount of steel in 25-lb. sections at $30 per ton, but were told that if we would take twice as many tons in the form of 50-lb. sections we could have the remainder at $10 per ton. That is precisely what we are told in effect, as respects the quality we are really buying—STIFFNESS—when we are offered rails of such sections at a uniform price per ton.

995. THE ULTIMATE STRENGTH of rails is a less important quality than the stiffness, because it is never expected to be called fully into use. Nevertheless, it often is so called into use and even exceeded, especially as the rail wears out, and it is therefore an important quality. The strength is less affected by the weight of the rail than the stiffness; for, referring to Fig. 245 once more, the strength varies only as the square of the height, whereas the stiffness varies as the cube, both varying directly as the width. Therefore, in a similar way to that employed for

TABLE 196.

COMPARATIVE AMOUNT AND COST OF STRENGTH IN LIGHT AND HEAVY RAILS.

Weight of Rails. Lbs. Per Yard.	Cost Per Mile at $30 Per Ton.	Comparative Strength.	Cost Per Unit of Strength.	Comparative Value Received for $1.
10	$480	.089	$5.365	44.7 cts.
15	720	.164	4.380	54.8 "
20	960	.253	3.796	63.2 "
25	1.200	.354	3.717	70.7 "
30	1,440	.465	3.091	77.6 "
35	1,680	.586	2,870	83.6 "
40	1.920	.716	2,684	89.4 "
45	2,160	.854	2.530	94.8 "
50	**2,400**	**1.000**	**2,400**	**100.0 "**
55	2.640	1.154	2.288	104.9 "
60	2,880	1.314	2.191	109.5 "
65	3.120	1.482	2.105	114.0 "
70	3.360	1.656	2.028	118.3 "
75	3.600	1.838	1.959	122.5 "
80	3,840	2.024	1,897	126.5 "

The different columns are determined in substantially the same manner as in Table 195, except that the third column is as the $\frac{2}{3}$ *power* of the weight per yard, taking 50-lb. rails as the unit of comparison.

determining stiffness, we may determine that the strength varies as the *square root of the cube* (or $\frac{3}{2}$ power) of the weight, and thus obtain Table 196. This table also should be carefully studied.

The loss of strength obtained with light sections will be seen from Table 196 to be far less striking than the loss of stiffness. Nevertheless, it is as if strength were a ponderable element, and we bought it in spite of the following prices per ton:

	Per ton.
Rails of 20-lb. section,	$47 50
" 30 " "	38 60
" 40 " "	32 30
" 50 " "	30 00
" 60 " "	27 40
" 70 " "	25 30
" 80 " "	23 70

If steel were quoted at these prices per ton, it is a tolerably safe hypothesis that light rail-sections would not be in much favor; yet this is an unduly favorable showing even for the item of strength, for if we were to compute the comparative strength after the sections have received a certain fixed amount of wear, we should find the apparent disadvantage of light sections as given above very much increased.

996. It is a little difficult to determine a standard by which to measure DURABILITY, because, as a rule, light and heavy sections are chosen for very different duties, i.e., are approximately proportioned, and necessarily must be, to the kind of locomotives running over them, so that no rational comparison can be made between the durability in a 10- or 20-lb. section and that in a 70- or 80-lb. section, as there can be in the items of stiffness and strength. What we can do, however, is to compare each section with one 5 or 10 lbs. heavier, since there is a rational and practical choice between such sections, for any one given service.

Taking a rude yet tolerably approximate average of rails as they are now designed and chosen, we may say (1) that half the total weight is in the head, and (2) that half, or nearly half, of

the metal in the head (or ¼ of the whole weight of the rail) is expected to be worn away before the rail is finally condemned as unsafe, although it may be earlier removed to a less trying location. That is to say, a 40-lb. rail has 10 lbs. of wear in it, and a 50-lb., 12½ lbs., making their weight when finally condemned 30 and 37½ lbs. respectively.

997. But when comparing two rails *for any one given service* it is obvious that this is an unfair basis of comparison, since, whatever the original weight per yard, a rail for any one given service may be so designed as to utilize most of any additional weight in wear, leaving the weights of the worn-out rails when scrapped nearly the same. This is, of course, not fully possible without using very ugly and distorted original sections, but it is at least a moderate statement that, even if any two rails of different weights are designed precisely "similar" to each other (as, say, Fig. 245), so that they have the same proportion of waste metal (as respects wear) in the base, yet the head can in all cases, in any one given service, be worn down to an equal ultimate weight before condemnation, so that a 40-lb. and 50-lb. rail would compare as follows:

	When New.		When Worn Out.		
	Head.	Base.	Head.	Base.	Total.
40-lb. rail, . . .	20 lbs.	20 lbs.	10 lbs.	20 lbs.	30 lbs.
50-lb. rail, . . .	25 lbs.	25 lbs.	10 lbs.	25 lbs.	35 lbs.

A 50-lb. rail worn down to 35 lbs. may fairly be said to be at least as strong and safe as a 40-lb. rail worn down to 30 lbs., although that is rather an extreme illustration as respects the absolute amount of wear for either of the rails specified; but by proper design it is realizable in sections sufficiently strong for their duty.

998. If, however, we are practising the last degree of economy in first cost, choosing the very lightest section which is consistent with the duty laid upon it, as we have already admitted is sometimes expedient, it is obvious that we cannot count on any such rate of wear as that. Wearing off half the head means reducing its ultimate strength by something like 45 per cent, and

TABLE 197.

COMPARATIVE AMOUNT AND COST OF DURABILITY IN LIGHT AND HEAVY RAILS.

Weight in Lbs. Per Yard.	Weight in Head only.	Available for Wear.		Left in Head after Minimum Wear.	Spare Metal in Next Heaviest Rail before Head becomes as Light.	Times Increase of Wear by Adding 5 Lbs. to Section.	Increase of Weight by Adding 5 Lbs. to Section.	Comparative Cost of the Durability in 5 Lbs. More Per Yard, taking the Durability of a Lighter Section as worth 100 Cents on the Dollar.
		Maximum. ($\frac{1}{2}$ Head.)	Minimum. ($\frac{1}{5}$ Head.)					
10	5.	2.5	1.	4.	3.5	3.50	$\frac{1}{2}$	$\frac{1}{7}$ or 14 cts. on the dollar.
15	7.5	3.75	1.5	6.	4.	2.67	$\frac{1}{3}$	$\frac{1}{8}$ or $12\frac{1}{2}$ " "
20	10.	5.	2.	8.	4.5	2.25	$\frac{1}{4}$	$\frac{1}{9}$ or 11 " "
25	12.5	6.25	2.5	10.	5.	2.	$\frac{1}{5}$	$\frac{1}{10}$ or 10 " "
30	15.	7.5	3.	12.	5.5	1.83	$\frac{1}{6}$	$\frac{1}{11}$ or 9 " "
35	17.5	8.75	3.5	14.	6.	1.71	$\frac{1}{7}$	$\frac{1}{12}$ or $8\frac{1}{3}$ " "
40	20.	10.	4.	16.	6.5	1.625	$\frac{1}{8}$	$\frac{1}{13}$ or $7\frac{3}{4}$ " "
45	22.5	11.25	4.5	18.	7.	1.55	$\frac{1}{9}$	$\frac{1}{14}$ or 7 " "
50	**25.**	**12.5**	**5.**	**20.**	**7.5**	**1.5**	$\frac{1}{10}$	$\frac{1}{15}$ or $6\frac{2}{3}$ " "
55	27.5	13.75	5.5	22.	8.	1.454	$\frac{1}{11}$	$\frac{1}{16}$ or $6\frac{1}{4}$ " "
60	30	15.	6.	24.	8.5	1.42	$\frac{1}{12}$	$\frac{1}{17}$ or $5\frac{7}{8}$ " "
65	32.5	16.25	6.5	26.	9.	1.385	$\frac{1}{13}$	$\frac{1}{18}$ or $5\frac{1}{2}$ " "
70	35.	17.5	7.	28.	9.5	1.357	$\frac{1}{14}$	$\frac{1}{19}$ or $5\frac{1}{4}$ " "
75	37.5	18.75	7.5	30.	10.	1.333	$\frac{1}{15}$	$\frac{1}{20}$ or 5 " "
80	40.	20.	8.	32.	10.5	1.312	$\frac{1}{16}$	$\frac{1}{21}$ or $4\frac{3}{4}$ " "

The manner of determining these various values is as follows:

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
	Half of Col. 1.	Half of Col. 2; $\frac{1}{4}$ of Col. 1.	$\frac{1}{5}$ of Col. 2; $\frac{1}{10}$ of Col. 1.	Col. 2 − Col. 4.	No. in line below of Col. 2 − Col. 5.	Col. 6 + Col. 4.	Five lbs. + original weight in Col. 1.	Col. 8 + Col. 7.	\$1.00 × Col. 9.

its stiffness by 65 to 70 per cent (making merely a rough estimate of the new "moments of inertia" and "radius of gyration" necessary to determine it exactly). When we are selecting a rail as light as we dare, we have no such margin as that; yet we must assume some margin for wear, for however light a section may be, it cannot be expected to become unserviceable as soon as the top is fairly polished. We may assume, perhaps, that, in such cases, a wear equal to ONE FIFTH of the metal in the head is more or less consciously contemplated and actually realized. With these premises, we may determine in Table 197 how much durability we get for a dollar with light and heavy sections, and it will be seen that—of all the three qualities we are buying—the worst sacrifice by far is in buying durability in light sections. It is as if when buying rails we were buying steel instead of durability, and chose the light sections in the face of the following market quotations of steel:

	Per ton.
Steel in 20-lb. sections,	$30 00
Additional lots (spot cash for future delivery, as needed, at end of — years),	2 75
Steel in 40-lb. sections,	30 00
Additional lots,	2 31
Steel in 60-lb. sections,	30 00
Additional lots,	1 76

Of course this enormous difference is due not so much to the extraordinary cheapness of the durability in the heavier sections as to the extraordinary dearness of the durability in the lighter sections. Still, if we assume that we get our money's worth out of the light sections, the comparison is a fair one. By varying the assumed rates of wear, the numerical comparison will be modified accordingly, but in no probable case enough to make the moral materially different.

999. Of course, too, it is to be remembered that durability is a quality for future delivery (for light-traffic roads, perhaps, in a very distant future), which we pay down for now, in cash. It is therefore only the PRESENT WORTH of this future value which we ought to consider. Still, this applies only to the durability.

The strength and stiffness we have use for from the very day the rails are laid; and even the present worth of the extra durability at the largest probable rate of interest and the longest probable life of light rails is cheap indeed at the price paid for it, as will appear from Table 18, page 82, or more directly from the following Table 198, which explains itself, and will probably make it very clear that whether a new project AS A WHOLE will pay or not, it is almost sure to return a heavy profit on the ADDITIONAL capital invested, obtained at any probable cost, to buy reasonably heavy rail-sections, for the sake of their durability alone.

TABLE 198.

YEARS OF WEAR WHICH A LIGHT RAIL-SECTION MUST OUTLAST BEFORE THE DURABILITY OBTAINABLE BY ADDING FIVE LBS. PER YARD TO IT WILL BECOME A LOSING BARGAIN, COSTING MORE THAN THAT OF THE LIGHT SECTION.*

WEIGHT OF LIGHT SECTION. Lbs. Per Yard.	PRESENT COST OF CAPITAL.			
	5 per cent.	10 per cent.	15 per cent.	20 per cent.
	Years.	Years.	Years.	Years.
20	45.0	23.0	15.7	12,0
30	49.1	25.2	17.2	13.1
40	52.0	26.6	18.1	13.9
50	55.5	28.4	19.4	14.8
60	58.1	29.7	20.6	15.5
70	60.3	30.9	21.1	16.1
80	62.4	31.9	21.8	16.7

* For the ultimate value, U, of a certain sum p invested at compound interest for n years at r per cent, we have

$$U = p(1+r)^n;$$

whence

$$\log U = \log p + \log(1+r) \times n,$$

and

$$n = \frac{\log U - \log p}{\log(1+r)}.$$

Letting the numerator (1) of the vulgar fractions in column 9 of Table 197 $= p$ (the log of which is 0 and may be dropped), the denominator of the same fractions will $= U$, and we have

$$\log n = \text{log of} \log U - \text{log of} \log(1+r).$$

1000. In these facts we have reasons enough, and to spare, why all roads should tend, as they do tend, to use what projectors of new roads call a "heavy' rail, and think they can't afford. It is because, for a poor road as well as a rich one, THE BEST IS

1002. TERMINAL FACILITIES, for instance, are an immense item in the investment in large railways. In the Buffalo (N. Y.) yards alone there are 650 miles of track (Table 203), representing an investment of millions. Station and other buildings are other large items, which may be made small on a light road; but the chief of all directions in which a rigid yet intelligent economy may be exercised to reduce largely the construction account without undue effect upon earning capacity is in the construction of the road to sub-grade.

1003. This is best seen by considering how much (or rather how little) the cost of 5 lbs. per yard extra weight in the rail, which we may take at the even figure of $30 per ton, or $240 per mile, will do to construct the road to sub-grade. We have seen how very advantageous is the effect of this expenditure upon the rail-section. If expended on grading and masonry, the same amount will only do the following:

	Cubic Yards.
Earthwork, at 20 cents per cubic yard........................	1,200
Equal to a continuous fill 5 in. deep, or a cut 10 ft. deep and 100 ft. long.	
Rock cutting, at $1.50 per cubic yard........................	160
Equal to a cut 100 ft. long and 2.3 ft. deep.	
Culvert masonry, at $5 per cubic yard........................	48
Or one small box culvert.	
Bridge masonry, at $10 per cubic yard..................only	24

Far more than these quantities can usually be saved by abandoning the attempt to fit the line for high speed and long trains, and judiciously economizing in these three ways: (1) By using sharp curvature; (2) by using trestling in place of masonry and heavy earthwork; (3) by moderate undulations of grade; to which may be added (4) sacrifice of distance to obtain easy work, and especially to reach towns.

1004. Whatever conclusion may be just as to the proper STANDARD OF CURVATURE for lines of fair traffic, it is certain that for a road to which the last degree of economy in first cost is essential, and which does not expect more than a very light traffic, the intelligent use of sharp curvature offers one of the simplest, most

effective, and most expedient methods of economizing in first cost. We have seen that since the introduction of steel rails and air-brakes both the operating cost and the danger of sharp curvature have been greatly diminished. The New York elevated railways run 800 or more trains of four cars each per day around the 63° curves (shown in Figs. 201–2) with perfect ease and with only a moderate slackening of speed. Another much-used curve of 50 ft. radius is described on page 326. In Table 116 full details are given of other sharp curves in use on standard-gauge lines, ranging from 410 to 175 ft. radius, over many of which a very heavy traffic passes. While these extremes are to be deprecated (nor are they often required), they do make it an absurdity to say that a cheap light-traffic railroad may not use almost any curvature which the nature of its route calls for in order to reduce first cost, whatever its gauge.

In a country offering any difficulty, the reduction which can be effected in this way is very large indeed, and it will in general be found that no excessive reduction of radius is needed to give a line closely approximating to a surface line, and fitting so well that any further reduction of radius will save but little (par. 883). This disadvantage is far less than that of light rails in almost every instance.

1005. Moreover, if the profile of almost any line be studied, it will be found that THE EXPENDITURES ARE LARGELY CONCENTRATED AT SINGLE POINTS. Four or five cuts in a mile, eight or ten miles in a hundred, are what bring up the average; so that in seeking the last degree of economy *at these critical points* the line as a whole is not, after all, so seriously modified as would be imagined. A further advantage, or rather a bright side to the disadvantage of so economizing by sharp curvature is that at many points the works may assume a mere temporary character for present necessities, while being adapted for ready improvement in the future, when and if means exist for doing so. In this way the necessities of both the present and future are better provided for than if a compromise line were chosen in the beginning which did not fully insure either present cheapness or future excellence. Par. 283 gives a notable instance.

1006. Here the question of GAUGE naturally comes up. Among the many advantages which have been so loosely claimed for the narrow-gauge system, perhaps none has been so insisted on, or so affected the popular imagination, as this one of being able to use sharp curves readily which were all but impracticable with the standard gauge.

A few years ago, when the first edition of this treatise was issued, no discussion of the question of light railways could have been adequate without entering pretty fully into the *pros* and *cons* of the gauge question. This is no longer necessary. The irresistible logic of events has practically settled the question, and the belief in the narrow-gauge as an expedient and defensible system of construction, which was from the beginning founded chiefly on illusion and delusion, is rapidly passing away, and all but gone. We may therefore merely summarize briefly the leading points of the question.

As respects curvature, we have already seen (pars. 335–6) that while the gain in curve resistance from a narrowing of gauge only, with no other change, is very slight, yet when the wheel-base is reduced correspondingly the curve resistance is probably diminished about in proportion to the gauge. As this is what is usually done in practice, we may consider it from that point of view.

1007. But the question then arises: What is saved thereby? If it be to increase the hauling capacity of engines, a very slight additional curve compensation will neutralize the extra resistance of the wider gauge, and we have already seen (par. 290) that any radius which is likely to be desired is readily practicable for properly designed standard-gauge engines. If it be to save the extra wear and tear and loss of power, a small reduction in an item the whole of which is so small (Table 115, page 322) is not worth any considerable sacrifice, nor can it be taken for granted (nor is it probable) that there is any such reduction.

1008. As respects rolling-stock, there cannot be a question that there is absolutely no practical advantage in the narrower gauge. Any reputable locomotive-builder will contract to build

engines of the same weight and power for either gauge, which will traverse the same curves, for the same price. The standard-gauge engine, in fact, will or can have enough shorter wheel-base, because of its greater width, to make it take curves a little better—a very important point which narrow-gauge advocates and opponents alike have almost wholly lost sight of.

The same is essentially true of the cars. The car-bodies may be exactly the same, and the trifling loss from the extra width of trucks, if it were worth discussing at all, may be fully made up by a slight increase in the weight and capacity of the car-body, while car-bodies of the ordinary size and capacity can go safely over any structures or track which will carry a light locomotive—whether standard-gauge or narrow-gauge—and carry as large a proportion of paying load as is customary in narrow-gauge cars.

1009. The bridges and trestles are, of course, not affected by the width of the gauge, if rolling-stock of the same weight and width pass over them; besides which, we shall shortly see evidence (par. 1039) that the cost of bridges is but very little affected by the load per lineal foot they are built to carry, so that there is little real inducement to build such structures to carry less than the common loads.

The earthwork and masonry is affected only by whatever difference there may be in the width of the road-bed, which cannot properly be more than the difference of gauge. The ties, we shall soon see (par. 1056), may be made somewhat shorter, or about three quarters of the usual width, but only at the expense of decreasing the stability of the track and increasing the labor required.

Fencing, right of way, buildings, frogs, switches, side-tracks, shops, etc., etc., are not affected at all, if the standard of excellence and weight of rolling-stock be the same.

1010. There remains, therefore, as the net gain from the narrower gauge, only the slight saving in grading and ties, which may amount to one to four per cent of the total cost of the line.

On the other hand, there are several very serious losses. The

one which is alone of decisive importance is the great loss from not being able to exchange traffic in bulk, but having to transship all freight and passengers. The loss from this is far more than its direct cost. The resulting inconvenience, delay, and damage to freight drives away much traffic.

The cost of maintaining track to a given standard of excellence is likewise greater, the cost for track-labor being in about inverse proportion to the length of the ties. The less bearing area of the ties on the ballast increases this disadvantage materially.

The maintenance of rolling-stock is decidedly more costly in proportion to work done, and the train resistance higher, because of the smaller wheels. The speed is necessarily lower, and the passenger cars less comfortable.

These facts are now admitted by all intelligent managers, whether of broad or narrow gauge, and the reconstruction of narrow to standard-gauge is now going on with great rapidity, Several thousand miles of narrow-gauge lines have already been changed, and it is plainly only a matter of a few years when practically all the remaining lines will be changed.

1011. It is often apologetically admitted by those otherwise opposed to the narrow-gauge that for certain mountainous regions it is best adapted. This likewise is an error, except for such few lines as are not likely to either have or desire traffic relations with other roads.

An example is the great system of narrow-gauge lines in Colorado. The Denver & Rio Grande was projected in the early days of the narrow-gauge movement, and did much to extend it, if indeed it may not be said to have been the origin of it, as it certainly was the source of its temporary strength. It is by much the most considerable narrow-gauge system in the world, and for many years was a great financial success; nor are its later troubles to be ascribed primarily to its gauge, but to bad judgment in extensions and other expenditures.

Nevertheless, the success of this line had little or nothing to do with its gauge, but was due rather to the fact that it was

cheaply built, and was assured a monopoly of a remunerative and growing traffic at very high rates—rates from three to eight times higher than were usual on lines farther east. The disadvantages of a break of gauge were likewise reduced to the minimum by its location. Its narrow-gauge system was complete in itself, and connected with standard-gauge tracks at but a few points, where transshipment was often no disadvantage.

Yet even under these circumstances—the most favorable under which any large narrow-gauge lines have ever been placed—the disadvantages of the gauge have proved so serious that it is now (1887) only the lack of means which prevents the immediate widening of the gauge on all the more important lines. To do this involves little expense. The ties are rather short for the purpose; but the 20° and 24° curves can, in the first place, be passed without difficulty by the standard-gauge engines, and, in the second place, the cost of reconstructing such curves as are objectionable, while it may be a considerable absolute sum, will be a very trifling one in proportion to the total investment, and probably far less than the present yearly loss from the narrower gauge.

1012. The use of a narrower gauge to cheapen construction has been proved by actual experience, therefore, to be in all cases inexpedient for any road handling a general traffic, or having any reasonable chance of wishing to exchange traffic with other lines.

1013. Returning to the more hopeful directions for economy: the free use of WOODEN TRESTLING and the practical abandonment of the (immediate) use of masonry is another legitimate and wise device for reducing first cost.

There are not a few engineers who decry the use of wooden trestles, nor can it be denied that they are often ill and dangerously built, and then neglected so long that they become a frequent source of accident. But when properly built and properly kept up, they furnish a safe and cheap method of avoiding or postponing the more costly features of construction, so that, even for roads of considerable traffic, it is far wiser to preach

the gospel of sound construction than to decry their existence. Fortunately, under existing conditions in America, most of the localities where very light railways only can be supported are near enough to local timber supply to obtain pine, hemlock, or other suitable trestling timber at very low prices; and with split stringers, and split sills and caps, it is easily possible (without going into fuller details, which would be inappropriate in this volume) to erect substantial structures, without mortises, in which each individual stick is renewable in detail, and which will be as safe for the passage of trains as any bridge, so long as they are properly maintained. The great majority of the trestles now erected in this country, however, are ill-designed, especially as respects the floors.

1014. At somewhere from 10 to 15 feet of height of fill such a structure becomes cheaper in first cost than even a plain earth fill; and when, in addition to the fill, there would have to be a masonry structure, or when, if it were not for the trestle, the grade would have to be dropped or the line swung in so as to give a rock cut (or even a heavy earth cut) at each end of it, the trestle becomes very much cheaper, and its free use affords us a solid and safe roadway for immediate use which can be continued in the same form indefinitely, if poverty requires it, or which can be advantageously and economically replaced by more permanent structures at any time, using trains to make the fills and supply the stone.

1015. It is also allowable to use WOODEN BOX CULVERTS, to be replaced in time, as they begin to decay, by iron pipes placed inside of them. Many great roads where stone is scarce build these in place of open culverts or trestles as a regular practice, and much can be said for it. No road, of course, would use wood for box culverts when stone could be obtained at reasonable cost.

1016. The use of moderate undulations on gradients affords another means by which the first cost of a line may often be largely reduced, and we have seen (par. 397) that if the track be good enough to stand a certain moderate increase of speed at

special points, it involves no injury to the hauling capacity of engines. The limits within which momentum can be relied on in this manner has been already considered (par. 441) and may, when economy is urgent, be closely approached, as in the instance of par. 832, because, should such undulations prove seriously objectionable, they may be taken out at any time. This is certainly a far wiser way of economizing than cutting down the rail so light that it will barely carry the engine, as is often done.

1017. Finally, one remaining device will complete all that is possible, or probably necessary, in the way of reducing the first cost of the road-bed. A great deal of money is spent by many roads which can ill afford the luxury in getting a short line. In the light of the facts brought out in Chap. VII. it is unquestionable that, however it may be with roads of large or of fair traffic, a cheap light-traffic railway which spends money to get a short line is burning its candle at both ends, and the engineer of such a line cannot too carefully remember that, although on the one hand its length may be the ruin of it, because it has to operate it, yet on the other hand it is its salvation, because its revenue depends on it.

1018. Especially is this true when, in choosing the easiest line regardless of distance, we not only obtain an easier line to construct, but one which will take us NEARER TO THE VARIOUS SOURCES OF TRAFFIC. However it may be with lines of larger traffic, a poor railway certainly cannot afford to pass by on the other side even quite small traffic points which, by going nearer to them, will add a little more traffic to the slender aggregate; not only because every little helps, but because the revenue per head of that population is also smaller, as we have seen in the preceding chapter.

1019. The truths which have been stated are not to be taken "neat," nor recklessly twisted to mean more than has been said; as, for instance, that it is ever expedient to lengthen a line *merely* for the sake of lengthening it, or that it is not worth while to try to avoid curvature, or that wooden trestles are as good as per-

manent works. It has been merely intended to show that, for a road which must practise the last degree of economy and which has little more than a turnpike traffic, the CONSTRUCTION OF THE ROAD TO SUB-GRADE is the proper place, and the most hopeful place, for "cutting to the bone," because an amount sufficient to give a decently solid superstructure can usually be saved out of the first construction with far less risk of injury and loss. This is apparent from Table 199, showing the percentages of

TABLE 199.

SHOWING THE PERCENTAGE OF COST TO SUB-GRADE ON VARIOUS ITEMS OF CONSTRUCTION ON VARIOUS LINES.

	I.	II.	III.	IV.	V.
Length, miles	60	100	14.5	46	15
Total cost per mile	$5,073	$7,490	$18,260	$18,920	$83,854
Clearing	2.1	....	0.2	2.0	....
Grading, Earth	71.0	61.9	51.0	35.1	25.7
Grading, Rock	....	....	7.5	....	50.3
Masonry, Culverts	....	6.1	11.0	....	5.4
Masonry, Bridge	....	13.7	13.5	5.8	9.8
Bridging	...	2.0	1.2	12.4	1.5
Trestling, etc	14.3	11.7	9.1	31.8	....
Fencing, etc	12.6	4.6	6.5	12.9	....
Tunnel	....	....	....	....	7.3
	100.0	100.0	100.0	100.0	100.0

CHARACTER OF LINES:

I. Chiefly light, with sections of heavy grading; no stone-work.
II. Moderately light grading, with sections of heavy; many structures.
III. Side-hill line, no surface work; very numerous structures.
IV. Light surface grading, two costly bridges only; much high trestling.
V. One of the costliest sections of mountain line in the United States.

The relative cost of another light Western road, several hundred miles long, was divided as follows, including all items, and not those to sub-grade only:

	p. c.
Engineering	2.3
Grading, including tunnelling	23.6
Bridge masonry	5.6
Culvert masonry	2.5
Temporary trestling	1.1
Superstructure, bridges and trestles	4.5
Ballast, and settling of embankments	3.7
Dressing up road-bed after winter	1.7
Right of way, fencing, cattle-guards and road-crossings	1.9
Rails and track-laying, complete	17.9
Cross-ties (very small)	2.5
Engine-houses, shops, stations, water supply, pumps, etc	6.9
Locomotives and cars	10.2
Interest on bonds to opening	5.8
Discount on bonds	7.7
Taxes to opening	0.1
Office expenses, salaries, etc., to opening of line	1.7
Incidental to opening of line	0.3
Total to opening of line	100.0

the cost to sub-grade of various items on different railroads, all of them of comparatively light (although not the lightest) traffic, and varying in character of work from moderately light to the very heaviest. The prices on all of them were from 25 to 40 per cent higher than now (1886) obtain, under favorable conditions; but in each case alike it will be seen how much less injury a saving of $240 per mile in some or all of the items given would probably have done to the road than if 5 lbs. per yard were cut off the rail-section.

1020. Nothing has been said so far about GRADIENTS, because a very light traffic road cannot afford to spend money to obtain more favorable gradients than careful study of the country will afford at the minimum cost, which (par. 894) will generally be quite reasonably favorable. At any rate, while the temptation for the locating engineer to magnify his office may be great, until provision has first been made for a reasonably substantial and well-maintained track, it may be taken as a tolerably safe general rule, that the same amount of money expended on track will add far more to the hauling capacity of the line than if expended to reduce gradients.

1021. Cutting the work down in the various ways suggested, with due care to do the minimum of injury to its efficiency, $3000 to $5000 per mile may be made to grade a very light railway through tolerably broken country, and this, of course, under favorable circumstances, may be reduced much lower. For such lines, intelligently planned, there is and will probably always be a very wide field. The trouble is that the economy is too often given a wrong direction, and the item which is ordinarily the first attacked—the rail-section—is one of the last of all to attempt to economize in.

1022. This may, perhaps, be made still clearer if we revert to the rail question for a moment to consider a little more exactly the RELATIONS OF RAIL TO TRACK-LABOR. Where is money for improving track best expended—in increasing the rail-section or in more track-labor? The stiffer the rail the less perfect need be the supports of the road-bed for equal excellence; but it is sometimes claimed that this needed support

can be more cheaply obtained by putting a little more work [illegible] facing, especially when extreme economy in first cost seems [illegible] It hardly needs more than a few contrasting figures to see [illegible] more an impression than a well-founded belief.

1023. To increase the weight of rail 10 lbs. per yard [illegible] numbers, 16 tons per mile, costing, at the even figure of [illegible] per mile, the interest on which is,

At 5 per cent,	At 10 per cent,	[illegible]
$24.00.	$48.00.	[illegible]

Equal to a cost in cents per train-mile, assuming [illegible] trains per day each way, of

	Cents per Train-Mile		
	At 5 p. c.	[illegible]	[illegible]
1 train per day, ...	3.29	[illegible]	[illegible]
2 " "	1.64	[illegible]	[illegible]
10 " "	0.33	[illegible]	[illegible]
20 " "	0.16	[illegible]	[illegible].6

1024. The common expenditure on [illegible] is about 10 cents per train-mile, as an average [illegible] cents per train-mile on roads of very [illegible] sum with the figures above, we see [illegible] erable traffic, which is a kind of [illegible] stability gained by adding 10 lbs. [illegible] give far more for the money [illegible] than the expenditure of an equivalent [illegible] labor for lining and surfacing [illegible] even if it cannot get money [illegible] of $48 per year per mile [illegible] fore the extra 5 lbs. per [illegible] track-labor to be a paying [illegible] more than that might be [illegible] when the rail was a tolerably [illegible]

1025. As respects the [illegible] built at great cost for [illegible] clear as that. In fact, for [illegible] say one train per day and [illegible] clear that it will not [illegible] requires, as the cost of [illegible] rail will in that case be [illegible] cents per train-mile.

1026. But granting that this extreme case can but rarely be approached in practice—because [illegible] there are few even of the lightest-traffic roads which do not run more than one train each way per day, and [illegible] few roads are so poor that, if the case is properly presented, they cannot raise a moderate additional capital for betterments which, whatever the profit of the enterprise as a whole, will return 10 per cent profit on their own separate cost—it may be reasonably maintained from the result of experience that even in this extreme case the extra weight of rail is the best use which can be made of the money. The very least which can possibly be spent for track-labor, surfacing and maintenance (par. 124) to keep a [illegible] in safe condition for the passage of one train per day, is from $[illegible] to $[illegible] per mile, with $50 to $100 additional for ties, or, say, $[illegible], including perhaps $100 more for yards and miscellaneous. The cost of one [illegible] lb. per yard extra weight, even at 10 per cent interest on capital, is only $[illegible] per year, for which slight increase of one fifth or one third in the interest charge on rails we have just seen (Tables 195, 196, 197) that we obtain an average increase, in a very light rail, of fully 50 per cent in the three elements of strength, stiffness and durability. Granting a road to be so poor that no increase whatever in total charges can be borne for any betterment, however great, beyond absolute necessities, is it certain that so great a difference in the stability of the rail will not enable one fourth of the otherwise minimum track expenditure to be saved, while yet leaving the track as safe and good as before? It is fairly even balance, indeed, under this extreme supposition. Unless the rails were very light indeed, it probably would not pay to increase their weight; but it is difficult to escape from the conclusion that under any ordinary conditions, with the lightest traffic, it plainly will pay to use a tolerably heavy rail before relying on track-labor to make up by better surfacing for its deficiency of strength, simply to save a slight additional investment of capital.

1027. If so, then as the traffic increases up to a comfortable average, as to six or eight or ten trains each way per day, there becomes plainly an immense economy in using heavy rails to save track-labor, so much so as to indicate strongly that the very curious similarity in weight of rails used on all roads in this country above the poorest class, despite the great difference in volume of traffic, is due, not so much to the use of too heavy rails on light-traffic roads, as the use of far too light rails for true economy on our more important lines, as, for instance, 60- or 65-lb. rails on trunk lines which would be acting more wisely to use 80- or 90- or 100-lb. rails. The difference is, however, that such lines are rich enough

to stand the resulting loss, whereas a poor road which permits its poverty to destroy it by buying an over-light rail, cannot. Some of our more prosperous lines have recently begun to break through this rule by using what are now called very heavy rails, but the exceptions are not yet so numerous as to do more than prove the rule. It is in every way probable that within a few years 80-lb. or 90-lb. rails will be the rule, and lighter rails the exception. The inertia from past precedents, which have come down to us from the days when rails were several times more costly than now, will in time be overcome.

1028. We are, therefore, again and more strongly driven to the conclusion, that the one thing on which it is dangerous to economize is the item which is often cut down first of all—the weight of rail. On the other hand, we are led to these conclusions as respects the details of alignment:

1. As respects the minor details, distance, curvature, and rise and fall, their effects to increase expenses are at best small, and when the traffic is very light become very small. They are, therefore, one of the first directions in which close economy is warrantable for very light roads.

2. In less degree the same is true of ruling grades. Much increase of expenditure to obtain lower grades than a careful study of the ground shows to be possible at a minimum expense is not warrantable.

3. Both the above conclusions are especially true when the objectionable details may be readily corrected later, when and if the traffic warrants it.

4. Temporary wooden structures to decrease the immediate outlay are the next most judicious direction for economy.

5. Economies which decrease the stability of the permanent way are the most objectionable of all.

6. Sources of local traffic which can be reached by any reasonable sacrifice should in no case be neglected.

CHAPTER XXIII

THE ECONOMY OF CONSTRUCTION.

1029. WE must necessarily assume, in considering the *pros* and *cons* of many of the details of construction (as in par. 13), that, the construction of the road once entered on, a little more or less money will not be a serious question, but that means will always be forthcoming, at some rate of interest or other, if only it can be shown that the ADDITIONAL investment will be profitable.

But while this is so far true in a small way that it is the only proper guide for planning the details of a line, yet it is undeniable that, when extended to larger questions, affecting considerable sums of money, it does not in all cases, nor in many very prominent cases, correspond with the facts; which are rather that A CERTAIN GROSS SUM ONLY is available, and when that is exhausted, if it has not been so expended as to complete all the more essential details of the line, the company becomes bankrupt, and the line passes into other hands—perhaps for lack of only a small fraction of the sum which has been already lavishly expended.

So many prominent instances of this have happened, that it is no more than common prudence to assume that there is imminent danger of it in the case of every new line, to the extent of guarding against it so far as is legitimately possible.

1030. This is the more true because of the fact alluded to on page 34, that money for new lines of importance or for extensive additions to old lines can, as a rule, only be raised in "good times." "Good times" are times of high prices, as Fig. 246 illustrates very forcibly, and are naturally followed within two or three years by "bad times." By that time the new line is per-

haps nearly built, and needs its last instalment of money, which latter is often a sum which it was not expected to need, and which was even refused when offered, for fear of letting in too

FIG. 246.—PRICES OF ENGLISH IRON AND STEEL RAILS (SHOWN BY SHADED LINES) AND OF AMERICAN STEEL RAILS, REFINED BAR IRON, AND NO. 1 PIG IRON, FROM 1855 TO 1886.

many "on the ground-floor"—and this money very often indeed has to be raised at great disadvantage, if raised at all.

Unfortunately, the order of time in which the various expenditures are incurred is such as to rather increase this danger. Many of the most essential expenditures come last of all, and many of those which may be most harmlessly curtailed or postponed come first.

The locating engineer is in particular danger of overloading his company in this way, because, from the order of time in which his work is done, he in effect hypothecates a large part of its funds to meet expenses which are not fully defrayed until near the very end of construction. Prudence indicates, therefore, that whenever there is even the slightest doubt of securing the money necessary, the work should, from the first (par. 7),

be conducted on the assumption that only a given minimum sum will be certainly available, and that from it enough should be reserved to cover the most necessary items at least. The question then arises: In what direction will close economy do least harm?

So far as it goes, the preceding chapter is an answer to this question, for the economies least harmful to a light road are likely to be also least harmful to a line of fair to large prospective traffic. It is, however, not a complete nor entirely pertinent answer.

1031. Perhaps the first of all directions in which economy should be sought, or rather the last one in which expense should be incurred, is in the BUILDING OR PURCHASE OF BRANCHES during the period of original construction. There are exceptions to this rule, as there are to all rules; but AS a rule, a point so important that a branch to it cannot be legitimately postponed until the main line is finished, is so important that the main line should be carried through it. Only in the event that all other expenses are certainly provided for, should the construction of main line and branches be undertaken simultaneously.

To give only a single example of the importance of this rule, the Canada Southern Railway Company, while it was building its main line to Chicago, carried on simultaneously the construction of the St. Clair branch, 62 miles, and an extension into Michigan from St. Clair; the Toledo and Detroit branch, 52 miles; and also involved itself in expenses to control an existing line to Niagara Falls. Had the money which went into these desirable but subordinate lines been concentrated on its main line, the latter would probably have been completed to Chicago, and would then, probably, have secured enough traffic to have saved its projectors from the almost total loss which the panic of 1873 brought upon them, in spite of certain unfavorable circumstances.

1032. Allied to the question of building branches is that of DOUBLE-TRACKING during original construction. If there is any reasonable doubt of securing funds to carry through the entire enterprise successfully, opening a single track only at first is certainly the next most reasonable method for a temporary economy, to insure that the means on hand shall not give out before the line is in working order, and on a business footing. If it be

reasonably certain that a double track will be needed in the near future, all masonry structures may be built at once for double track, which will involve but a small addition to the total cost of the road—ordinarily not over five per cent, and often much less. If it appear still more certain that a double track will be speedily needed, even the grading may be done in the first instance for double track, and grading and masonry together will not ordinarily increase the immediate capital required more than 10 to 15 per cent.

But as both the grading and masonry for double track can ordinarily be done to somewhat better advantage, on the whole, after the track is laid than before, the expediency of doing even this much immediate work to provide for the future is questionable, unless the financial condition of the line is very strong; and the following items for double tracking, at least, can always be postponed to advantage till the line is opened,—even if it is fully expected to immediately proceed with double tracking, and funds for it appear to be certain,—viz., the bridging, ties, rails, and ballasting.

1033. In IRON BRIDGING there is not, contrary to what is generally imagined, any economy worth taking the slightest chance for, in building double-track bridges instead of two parallel single-track bridges. The weight of a double-track bridge is increased about 90 per cent over a single-track bridge of the same span, and for the same live load; and although the cost of the structure is not increased in quite the same proportion, yet when we take into consideration (1) even a year or two's interest at ordinary cost of capital; and (2) the depreciation and possible great need of the invested capital in the dark days of the first operation, the petty saving is not to be considered in comparison.

There is also a certain considerable operating advantage in having independent bridge-spans for each track, although the single structure is unquestionably the most pleasing to the eye. An accident to one structure leaves the other one available.

The superstructure of the double track complete, on a line

requiring double track, will ordinarily cost $10,000 per mile—a sum which has repeatedly made all the difference between success and failure.

If any line could be justified by the nature of its expected traffic in laying a double track at once, it was the West Shore Railroad, but had this policy been adopted by that line in respect to the double track and some similar matters, it would probably have saved it from bankruptcy.

1034. In Fig. 247 is given a diagram prepared by the writer from various data, but chiefly from formula for estimating the weight of bridges given in a valuable paper by Geo. H. Pegram, C.E., a bridge engineer of large experience (Trans. Am. Soc. C. E. 1885), which shows graphically several things of importance in respect to bridges.

It shows, *first*, how nearly a double-track bridge comes to being double the weight; *secondly*, how little saving is effected by building bridges to carry light loads; *thirdly*, the point at which the saving effected by using steel instead of iron becomes important; and, *fourthly*, the comparative weight of various spans by inspection.

If the truths which the eye readily grasps from this diagram were more generally understood and acted on, there would probably be less bad practice in railway-bridge construction.

1035. The third least objectionable direction for economy is the bold adoption of TEMPORARY LINES where permanent works of great cost will otherwise be required; meaning by "temporary lines" not those intended merely for construction purposes or for use until the permanent works can be completed, but lines good enough for several years' use at least without any great loss, leaving the better permanent line to be constructed only when it is certain that the traffic justifies and requires it, and means are available. Considerable amounts of distance, curvature, and rise and fall will not cause a dangerous loss in operation for a few years, if used only on the rougher sections as a substitute for more costly works later, and will enable the immediate outlay on the usually short sections (par. 1005), where the most costly works are concentrated, to be very materially reduced in many cases, as well as enable the line to be opened before an impending crash comes. The same is true in less degree of the use of TEMPORARY PUSHER GRADES of an objectionable character, but not so bad as to prevent the handling of through-trains.

1036. The fourth least objectionable economy, but one which, like the preceding, from its coming among the first in order of time, is apt to be one of the last practised, is the adoption as a standard, for the entire line, of a systematic economy (in money, but not in time or care) in respect to the minor details of alignment. The *pros* and *cons* of this question have been discussed so fully in the preceding chapter that we need not further enlarge upon it.

In these four ways (with which perhaps the USE OF TIMBER STRUCTURES, such as are shown in Fig. 249, might make a fifth) a very large economy may be practised which will almost assure that any project with any merit whatever will be so little burdened by its capital account that it will be able to live on what it can get to live on, even if, as it usually is, it is far below its expectations.

1037. Beginning now at the other end of the question, the most objectionable of all ways of economizing is much the commonest of all, for reasons already sufficiently discussed in Chap. III., omitting to go INTO, as well as TO, the terminal cities, and other important traffic points on the line. This error very largely arises from the fact that it is an expenditure which comes late in the history of construction, or can be made to do so.

Probably the next most serious injury which can happen to a line is neglect to secure best possible RULING GRADES, but this more often happens from a lack of care and skill than from a desire to economize, since the expenditure is incurred early in the history of construction and the importance of favorable grades is more generally understood than the best manner of securing them.

1038. Barring this error, the next worst form of economy which can afflict a line is what is more emphatically than elegantly called a "cheap and nasty" style of construction: LIGHT RAILS, POOR TIES, THIN BALLAST, NARROW ROAD-BEDS, POOR MASONRY, and LIGHT BRIDGES. These defects really save but little money, while the expense and the bad name which has resulted from them have sapped the life of many a line. It is far better to economize closely in all the details of location but the grades,

and sometimes even in the grades themselves, than to do this. The difference between a thoroughly adequate and solid road-bed, and as inferior a one as it will seem possible to tolerate, will

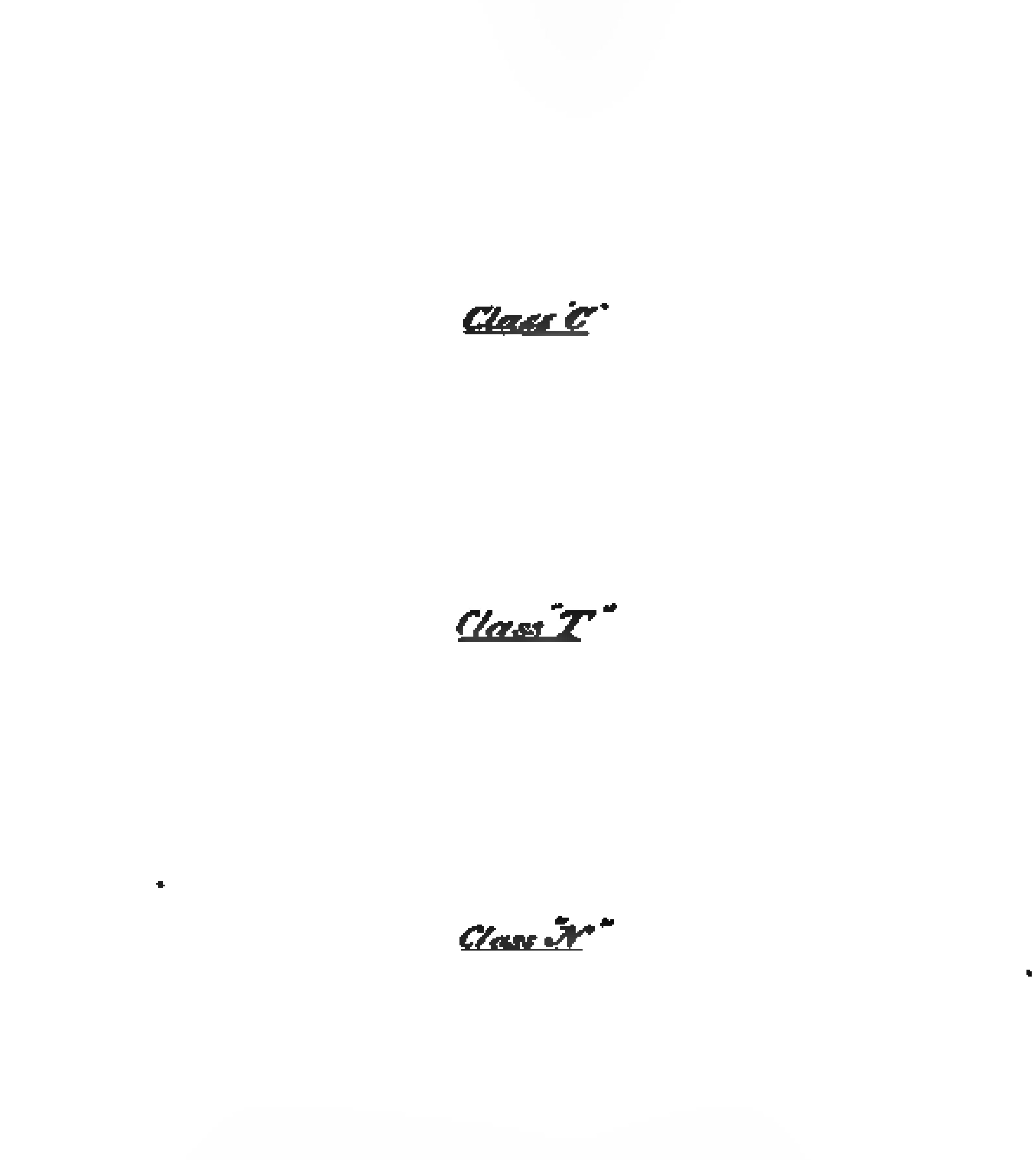

FIG. 248.—ENGINE LOADS USED IN COMPUTING THE WEIGHTS FOR FIG. 247.

rarely be more than $2000 to $3000 per mile; and on work at all heavy it is not difficult to save that sum by economizing in location, using temporary but solid wooden structures, and the other expedients noted above. These latter economies will not add

* This engine is not properly a mogul, but a ten-wheel engine.

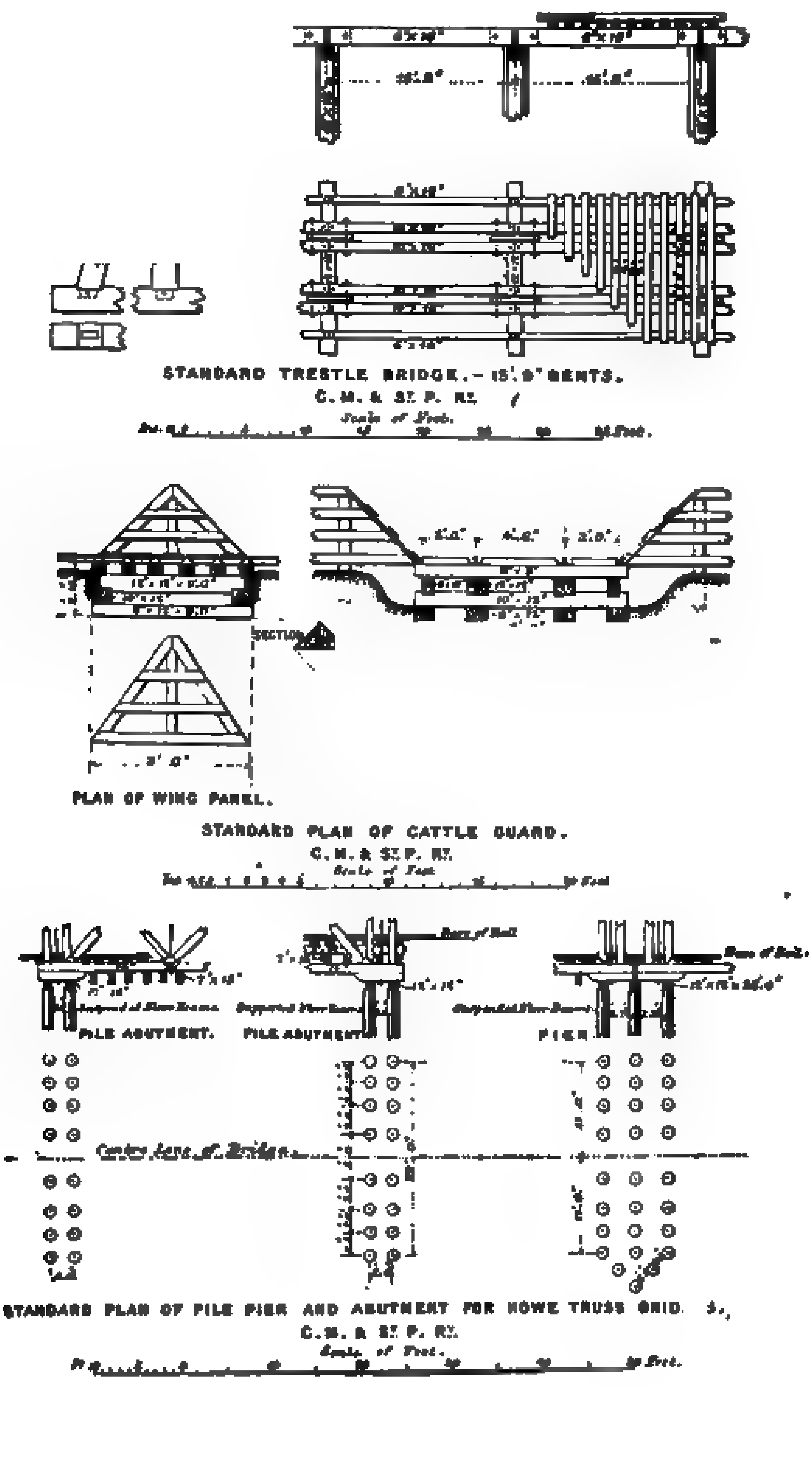

FIG. 249.—STANDARD WOODEN TRESTLE CATTLE-GUARD AND PILE ABUTMENT, CHICAGO, MILWAUKEE & ST. PAUL RAILWAY.

NOTE.—The design for timber trestles can be considered commendable only for quite low structures, split caps and sills (par. 1013) being in general preferable, as also split stringers. But the floor is excellent, and could only be improved by bringing the ties nearer together. Pile abutments, such as shown, are also quite safe and secure for a good many years; more so than poor, cheap masonry.

materially to expenses during the first ten or fifteen years on operation, whereas a poor and flimsy superstructure entails a large and constant addition to maintenance expenses.

1039. The loss which results from light bridges is proportionately quite as great as from light rails, as is made evident enough, without further discussion, from Figs. 247–8 and Table 200. The proportionate loss from poor masonry is even greater. It is far better to put up temporary wooden structures altogether, than to put up such flimsy masonry as is often built. That so very large a part of the masonry put up on new Ameri-

TABLE 200.

COMPARATIVE WEIGHT AND COST OF BRIDGES, TAKING BRIDGES OF "T" (TYPICAL CONSOLIDATION) TYPE, FIG. 249, AS UNIT.

CLASS OF LOAD. (Fig. 249.)	MINOR SPANS OF—					
	30 ft.	50 ft.	80 ft.	104 ft.	150 ft.	201½ ft.
T	100	100	100	100	100	100
C	98.74	98.05	97.10	96.33	94.98	94.00
M	97.73	96.47	94.56	93.16	90.75	88.61
N	(Uniform at 75.00).					

LARGER SPANS.

	201½ ft.	320 FEET.		420 FEET.		516 FEET.	
		Iron.	Steel.	Iron.	Steel.	Iron.	Steel.
T	100	100	100	100	100	100	100
C	93.34	91.11	89.55	88.77	89.55	88.21	89.55

The above shows at a glance that the effect of rolling load on weight of bridges is small, and the following will perhaps more fully show how petty is the economy:

	"Typical" Cons'n.	Consolidation.	Mogul.
For engines weighing (tons)	86.0	80.07	138.0
Or in the proportion of	100.	93.8	80.7
And for a load behind engine, per foot of (lbs.)	3,000	2,240	1,820
Or in the proportion of	100	85.4	73.0

TABLE 200.—*Continued.*

		Per Cent.	Per Cent.
Giving a loss per cent in rolling load over the strongest type of bridge of	Engine,	6.2	19.9
	Cars,	14.6	27.0
The saving per cent in *weight* (not cost) of bridge is only – for spans of	30 ft.	1.26	2.27
	50 "	1.95	3.53
	80 "	2.90	5.44
	104 "	3.67	6.84
	150 "	5.02	9.25
	201½ ft.	6.00	11.39

Beyond these spans the comparative difference becomes greater, so that we have for the difference between a rolling load of the "typical" and ordinary Consolidation type (neglecting the Mogul type) the following :

		Iron.	Steel.
For spans of	201½ ft.	6.66	....
	320 "	8.89	10.45
	420 "	10.23	10.45
	516 "	11.79	10.45

Thus even the largest spans do not increase in weight as fast as they increase in capacity, and on the shorter and more common spans an increase of only 3 to 6 per cent in weight gives 15 to 25 per cent increase in carrying capacity.

can lines should give out within a few years, as it does, either because the foundations were inadequate or were not properly protected against wash, or the stone poor, or laid dry, or the spans inadequate, reflects little credit on engineers.

1040. A still less reasonable and creditable mode of economy is CUTTING DOWN THE ROAD-BED, especially in cuts. The saving is but trifling, and the effect on maintenance expenses very unfavorable, since it forbids proper ditching, impedes access of the sun to the road-bed, and makes difficult to apply a proper coat of ballast and leave any ditch at all. The narrowest road-bed in earth should be 20 ft., especially in light work, or on light grades having many long low cuts on them, which latter are very difficult to drain. In fills, a 15-ft. or 16-ft. road-bed is none too wide, and will rarely be found to be much wider than is necessary to hold the ballast when the track is laid.

1041. Cutting down the coat of BALLAST is likewise one of the most costly economies in which a road can engage. Sometimes it is necessary, because ballast is not readily available, and to some extent good DITCHING may be substituted for it, but economy requires that both ditching and ballast should be good.

It was a saying of the late Charles Collins, the lamented chief-engineer of the Lake Shore & Michigan Southern Railway, that "two feet of ditch is worth one foot of ballast," and this has a foundation of truth at least, as was shown by the results of free ditching on the Lake Shore road. It may plausibly be claimed that when a road is neither well ditched nor well ballasted a limited amount of money will accomplish more good if spent for ditching than for ballasting, and there is a certain absurdity in putting on a thick coat of clean ballast in a cut where the ditching is so imperfect that there can hardly be said to be any. Nevertheless, more and better ballast is a crying need on many lines of considerable traffic, if not on most lines not of the first rank, and if it were more generally realized how cheaply ballast can be supplied by improved modern appliances, and how greatly it would decrease wear and tear and maintenance expenses, both of track and of rolling-stock, as well as sometimes increase by a car or two the length of trains, there would not be so many roads as there are practising an expensive economy in this item.

1042. One reason why ballasting is often so costly, even with all the advantages of steam-shovels and unloading ploughs, is an abuse (or what is often such) in THE HANDLING OF BALLAST TRAINS which may well be noted. Fair average prices for ballasting with steam-excavators and gravel trains may be taken to be as follows:

All expenses connected with loading	3	cts. per cu. yd.
Loading and delivering on road-bed, 10 mile haul	10	" " "
" " " " " 20 " "	15	" " "
" " " " " 30 " "	20	" " "

Not unfrequently, however, the cost will rise to two or three times these figures, because of interruption of trains.

This results because the ballast train, in disregard of all considerations of economy, and without the excuse of any real necessity, is all but universally treated as a kind of outcast or pariah among trains. The extent of its privileges is embodied in the stereotyped formula that it "has permission to work between A and B, keeping out of the way of all regular trains." What that means, on a road doing any considerable business, with all the necessary delays for clearing the track "ten minutes ahead of all regular trains' time," and for waiting for them to arrive when late, is an enormous proportion of lost time per day, doubling and trebling the necessary cost of delivering ballast on the track, not only in many but in most cases.

Nevertheless, this limitation of privileges is natural enough and well enough as a matter of permanent rule. A ballast train cannot be anything else than an irregular train, and cannot safely be given any rights whatever, except by special order; but therein lies the difficulty. Trains are, as a matter of fact, almost all run by special order, and when giving such order, it rests entirely with the discretion of the dispatcher, within wide limits, to favor one train or another as he sees fit. This discretion, however, is rarely exercised to prevent delays of ballast trains, which cost money, rather than delays of regular trains, which do not directly cost money; but the ballast train gets from the dispatcher, improperly and unwisely, much the same kind of treatment that it necessarily and properly has in the printed rules and time-tables.

Now a regular freight train is earning perhaps $1.50 per mile run and costing $1, but it will earn no less and cost no more (barring a slight loss of fuel) for being a quarter or half an hour more or less upon its trips. On the other hand, the total expenses for running a steam-excavator with perhaps three or four engines at work to handle the cars, are from $100 to $150 per day. A delay to any one of these trains is to a considerable extent a delay to all and to the excavator as well, and a delay of three hours per day to these trains (which is about a minimum) means the loss of $1200 to $1500 per month.

Under these circumstances what ought to be done, if true economy is to be considered, is to prepare something like a regular schedule for the movement of these trains, from day to day and from week to week, for the use of the dispatcher; to provide as good facilities as possible for communicating orders to them, and to require that, whenever and wherever it is possible without too great delay, the gravel trains shall be favored at the expense of the ordinary freight train.

1043. Supposing the delays to gravel trains to have been reduced to a minimum, there are few expenditures so directly profitable as to procure a steam-excavator and ballast plows, and keep two or three trains at work for a good part of several seasons increasing the depth of ballast. Half a cubic yard per cross-tie will raise the track some 8 in., and where the road-bed is wet and the haul not too great, this would not be so very bad an investment, simply as a preservative of cross-ties.

An additional economy for this kind of work on many lines, and one deserving of more frequent use, is the hauling of side-dump cars loaded with ballast on regular trains, especially way freight, whenever, as is frequently the case, eight or ten additional cars can be hauled over a portion of the division as well as not, owing to more favorable gradients. Many types of cars

suitable for this purpose exist which are readily dumped by one man.

1044. One of the very worst places to economize in, but fortunately not a common one, is in the CROSS-TIES. The number of these cannot be too great for economy, until they become so close as to impede tamping, which is when about 40 per cent of the length of the rail rests upon ties. Up to this point even the weight of rail may be judiciously sacrificed, if necessary, to increase the tie support, as may be speedily shown.

Track is constructed and made passable by the use of three agencies: (1) rails, (2) cross-ties, (3) tamping under the ties. Some proportion of each of these must be used to maintain a stable track, but in proportion as the stability from one of them is increased, that required from one or both of the others may be decreased. If we have a stiffer rail, we may use less ties and less track-labor. If we have more or better ties, we may use a

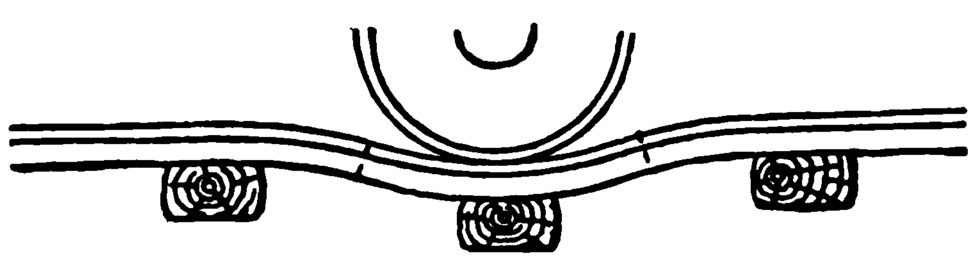

FIG. 250.

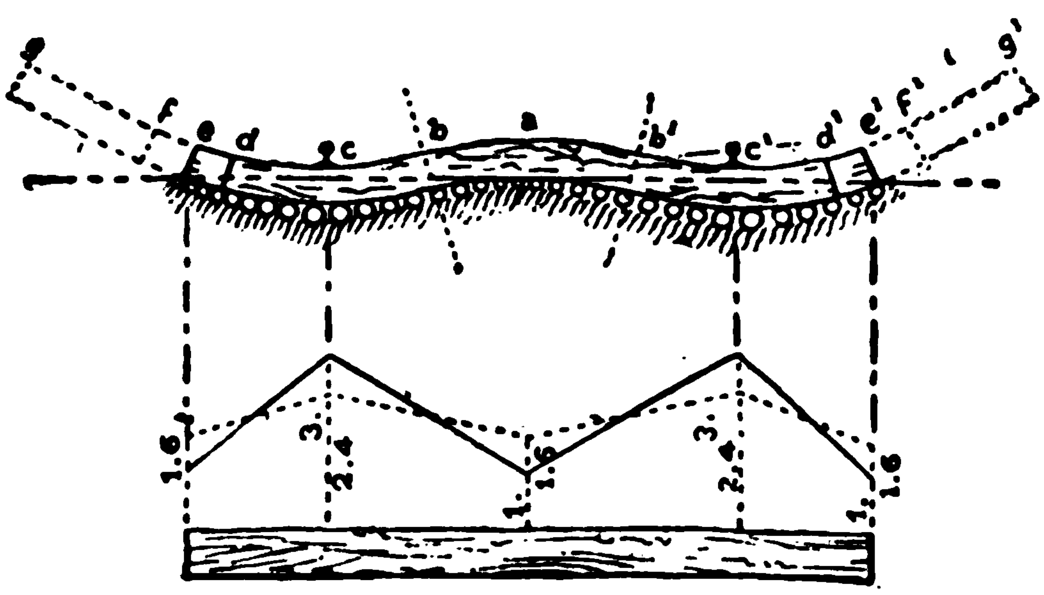

FIG. 251.

lighter rail. If we put more labor into maintenance, we may dispense with some expenditure on either rails or ties, or both. The different modes of yielding, outlined in Figs. 250 and 251, which occur more or less on all track, may be assumed to arise, and will arise, from deficiencies in any one of these three re-

quirements, either the rails or ties or tamping, and may be cured, in part or whole, by spending more money on either one of them. Assuming as a standard of comparison a 6×8 in. tie 8 ft. long, spaced 2 ft. apart, or 2640 per mile, the following combinations of spacing and width will afford an equal bearing-surface of ties on the road-bed and of rails, but will be seen to afford a very unequal support to the rail:

Ties per mile	2,640	3,000	3,168	3,520
Distance apart, centre to centre	24 in.	21.12 in.	20 in.	18 in.
Average width of face	8 in.	7.04 in.	6.67 in.	6 in.
Clear space, tie to tie	16 in.	14.08 in.	13.33 in.	12 in.
Comparative stiffness of same rail for each span	1.00	1.47	1.73	2.37
Comparative weight of rail to give same stiffness	1.000	0.825	0.761	0.650

The method of determining the comparative stiffness and comparative weight of rail in the last two lines is the same as used in par. 992 for rails, and need not be repeated. Whether we compute the comparative stiffness of the rails for spans from centre to centre of ties, or for one clear span between ties, or for spans omitting one tie, as in Fig. 250, the result is the same, although the absolute stiffness will of course vary greatly.

1045. Taking the extremes of the table above, we see that the addition of 880 ties, or one third increase, gives so much additional support to the rail that (assuming the support to each tie to be the same) a rail only two thirds as heavy will distribute the load as well from tie to tie. Not forgetting that stiffness is only one of the three qualities in a rail which are gained by increasing its weight, this great difference still indicates that increasing the number of ties to the extent of practical possibility (their dimensions remaining the same) adds much more to the aggregate stiffness of the track than the same amount spent on rails; as thus:

The cost of 880 more cross-ties per mile, more than doubling the stiffness of the same rail, amounts—

At 25 cents, to	$220 =	7.14 tons rails at $30 =	4.5 lbs. per yard.
" 30 " "	264 =	8.80 " " " =	5.5 " " "
" 40 " "	352 =	11.73 " " " =	7.3 " " "
" 50 " "	440 =	14.67 " " " =	9.1 " " "

Comparing this with the figures in Table 196, giving the comparative stiffness of light and heavy rails, we have the following comparison for various light rails—for which rails only the comparison is at all close:

Original weight of rail, ...	20 lbs.	35 lbs.	50 lbs.
Stiffness in do. taken as	1.00	1.00	1.00
Adding 4.5 lbs. per yard (= cost of 880 ties at 25 cents each, as above) makes stiffness	1.51	1.27	1.19
Adding 9.1 lbs. per yard (= cost of 880 ties at 50 cents each) makes stiffness . . .	2.12	1.57	1.40
Whereas the same sum spent on ties increases the stiffness, as above, to . . .	....	....	2.37

1046. While the addition of so large a number of ties, without decreasing their width, can rarely be practicable, and while the comparison is not strictly exact for other reasons, this does indicate clearly the general fact, that increasing the number of ties to the limit of convenience is a cheaper way of increasing stability than increasing the rail-section, even for very light rails. On the other hand, the total stability which is obtainable from ties is limited by the number which it is possible to use, so that what these figures in fact indicate is that, in endeavoring to get the utmost stability at the least cost, the first essential is to use ties as freely as is possible, and the next essential is to decide between a heavier rail and more tamping to supply the deficit.

1047. The physical limit to the increase in number of ties, of ordinary standard width, is probably 2800 per mile; but if, as in the first table above, we consider the width of the ties to be diminished as their number is increased, this limit is considerably higher. There are quite a number of roads in the United States which use 3100 to 3300 narrow ties per mile with very satisfactory results. Remembering that the stiffness of a rail decreases as the cube of the span, it is obvious that by dividing up the bearing-surface among a greater number of ties, so that the aggregate area remains the same, we measurably obtain two desirable ends at once—we give much more effectual support to a weak rail, and we in general reduce, instead of increasing, the total cost of ties, since the cost of ties will usually increase faster

than the required minimum face. As, therefore, the necessary space between ties varies approximately with the width of face, and is about twice the face (so that full-width ties cannot be used with very narrow spacing), the utmost economy would seem to require that narrow ties spaced close together should be given a decided preference at the same cost for ties per mile when a light rail is to be supported, and there are few rails indeed in this country which cannot be said to be light in proportion to the duty imposed on them. It could not rationally be expected, indeed, that 6-in. ties spaced 18 in. apart, instead of 8-in. ties spaced 24 in. apart, would increase the stiffness of a light rail from 1.00 to 2.37, as the figures above indicate; yet we may justly conclude that it will be increased very greatly, with a possible decrease in the total cost of ties as well, where the supply of large timber is small. In not a few localities ties of 5- or 6-in. face can be had for but little more than half the cost of ties with 8-in. face.

1048. A great error is often committed in making ties too thin. A cross-tie is an inverted cantilever. In Fig. 251 we have a tie yielding, as they all do, more or less under a load; and by inverting Fig. 251 it will be seen that we may consider the tie as a cantilever beam, supported upon two piers (the rails) and loaded with a more or less uniformly distributed load. If the tie were perfectly stiff, it would be an evenly distributed load, and the pressure of the tie upon the soil would be uniform for every square inch of its bearing-surface. If the tie be very thin, the conditions of the exaggerated sketch will literally obtain. The middle and ends of the tie will then be able to transmit but little pressure to the ballast, and (since the total pressure transmitted must in any case be the same) an excessive and destructive pressure will be thrown upon the road-bed directly under the rails, causing rapid deterioration therein. This may be shown by the load-diagram below Fig. 251. Let us suppose that a tie be so thin, or the nature of the support so unyielding, that the load per square inch directly under the rail is *three times* as great as at the ends and in the middle, as shown by the full

line in the diagram below Fig. 251—a very common difference, if not, indeed, one almost universally exceeded in occasional instances, even on a very good track. An increase of stiffness which would double the load on these lightly loaded extremities would produce, as will be seen from the diagram, an absolutely uniform distribution of pressure, and although this can never be fully realized, yet it is plain that it may be approached.

1049. Now the stiffness of any beam, however supported or loaded, is in proportion to the CUBE of its depth (or thickness of tie) and of its lengths between supports (or the gauge). Any attempt to compute from these facts the absolute requirements, or distribution of load, with a given tie or gauge, would be preposterous. There is no absolute requirement, since, however well maintained the track, occasional ties are badly or unequally supported; and since the load is far more than sufficient to break any tie in two at the middle if only supported at that point (a dead load of 14,000 lbs. per wheel would probably break such ties the first time it was imposed), it is for these maximum demands, and not the average, that we must provide. Therefore, speaking comparatively only, and taking a tie 6 in. thick as the basis of comparison, we have the following:

Thickness.	Comparative Stiffness.	Thickness of Narrow- (3 ft.) gauge Tie of— Equal Stiffness.	Equal Strength.
5 in.	0.58	3.18 in.	4.30 in.
6 "	1.00	3.82 "	5.16 "
7 "	1.59	4.46 "	6.02 "
8 "	2.37	5.10 "	6.88 "

From this it is clear that although the nominal bearing-surface of a tie is not increased by increasing its thickness, yet that the *effective* bearing-surface is likely to be very materially increased by a very moderate increase of thickness. By increasing the thickness from 5 to 6 in., we nearly double the stiffness; by increasing it from 6 to 7 in., we increase the stiffness 59 per cent, giving the effect outlined below Fig. 251, in which the full line shows the assumed distribution of pressure with a tie 6 in. thick, and the dotted line the effect on the latter of thickening

the tie 1 in. Economizing in the thickness of ties, therefore, would seem to be one of the poorest ways of saving money.

1050. This is more fully seen by comparing the effect of difference of length. It cannot be attempted to consider the matter in detail, but a tie which is under fair conditions to permanently fulfil its office of distributing the load may be considered to curve into the three circular arcs shown in Fig. 251, from which it will be apparent that, under whatever assumptions as to the curve of flexure, there is a clear limit to the useful increase of length in ties at a point considerably within a length of twice the gauge, *f f'*. If the tie be made longer, as, for instance, extended to *f f'*, or, still worse, to *g g'*, either the extra length will carry little or no load (which is most likely), or, if the support nearer the rail has given way so as to throw load upon it, it will be very liable to break the tie.

If the tie be made shorter, the load thrown on the middle of the tie will be disproportionately increased until, if we conceive the tie cut off close to the outside edge of the rail, the load per square inch will, in the first place, be very greatly increased, and, in the second place, the strength of that portion of the tie between the rails, considered as a beam, is diminished by about one half and its stiffness about seven eighths; because the effective span of the beam has, by cutting off the projecting ends, been almost doubled, i.e., increased from *b b'*, Fig. 251, to *c c'*.

1051. For the most efficient service from ties, therefore, we have a certain quite narrow limit of length, the minimum being about 7½ ft., and the maximum about 8½ to 9 ft., for the ordinary gauge of 4.71 ft. It is clear from the above that any increase of length above 8 ft. gives a far less effectual way of disposing a given quantity of wood (to obtain an approximately uniform pressure on the ballast, and so keep down the maximum), than to increase the thickness, provided the nature of the timber permits it. The apparent gain of bearing-surface by increasing the length of ties from 8 ft. to 9 ft., and the apparent absence of gain in bearing-surface by increasing the thickness from 6 in. to 7 in., will be seen to be precisely the reverse of the true conditions,

and we may well believe that this deceptive contrast has been the chief cause for such awkward combinations as an 8½- or 9-ft. tie with only 6 in. thickness, which prevails with 6.1 per cent of the ties in the United States.

Neglecting the widths, as an indeterminate element not definitely fixed, the percentages for the entire United States of the various lengths and thicknesses of ties in use is as follows:

Lengths, . .	8 ft.	8 ft. 6 in.	9 ft.	10 ft.	Total.
Percentages, .	63.5	27.6	8.9	0 +	100.0
Thickness, .	6 in.	6½ in.	7 in.	8 in.	
Percentages, . .	54.4	3.8	41.4	0.4	100.0

While these variations are in part, and perhaps chiefly, governed by the conditions of the timber supply, they arise in part at least, we may safely assume, from mistaken views as to what is, abstractly considered, the best proportion for a tie. The best dimensions for a tie are about 7 in. thick, 8 ft. 6 in. long, and 7 to 9 in. face.

1052. There is another side to the question of masonry structures which may be briefly noted. While a structure, if built at all, should be well and solidly built, it does not follow that because a certain proportion of the structures of a line eventually wash out that they were therefore ill-designed. "The natural end of a tutor," says the Autocrat of the Breakfast-Table, "is to die of starvation. It is only a question of time, just as with the burning of college libraries." So in a certain narrow and limited sense we may say that the natural end of a culvert, and even of many bridges, is to perish in some excessive flood. The exceptional storms which come but once or twice in a century can hardly be fully provided for, for the reason that it is difficult to build any large number of structures with such an ample margin of safety as to insure that many of them will not eventually wash out.

For example, in 1886 there came some unusual storms which chanced to fall most severely on some of the Boston roads, which are about the oldest roads in this country, having been built

from 40 to 50 years, and had rarely suffered much from floods and washouts heretofore. As a consequence structures were washed out in considerable numbers (on the Old Colony there were 40 washouts), many of which were "supposed to be strong enough to resist any current," and had succeeded in doing so for half a century.

1053. Such occurrences will and ought to make engineers cautious; but we may remember, on the other hand, that to have insured that these structures should not have washed out, their original size and cost would have had to be nearly if not quite doubled, and a simple computation in compound interest will show that had this been done in the first instance the additional investment would have amounted at 6 per cent to 19.50 times the actual first cost. It follows that in 1835 even a certainty of saving the cost of duplicating the original structure in 1886 would have warranted barely 5 per cent additional expenditure. It is true that the bare cost of renewal does not cover the whole loss, for there is a loss from delay and danger of accident incurred by the washout in addition thereto; but on the other hand, to guard against all the contingencies which might arise in 1886, it would have been necessary in 1835 to have about doubled the cost of all the structures, since all may be assumed to have been laid out with equal care, and it could not have been foreseen which would be most tried thereafter.

All of which goes to show that when structures have been skilfully laid out to stand the ordinary contingencies of 20 or 30 years it is about all that is either practicable or justifiable, and that the remarkable storms which come only once or twice in a century are not in fact, and hardly can be, successfully guarded against. This is especially true because the worst effects of even the greatest storms are localized within quite narrow limits. The storms referred to were not by any means the worst for 50 years, except at a few spots. But those structures which washed out chanced to be at those spots, while the really greater storms which have washed out others in past years did not chance to fall so severely on these.

1054. The same is, in substance, true of INUNDATIONS of railway lines. Every year we hear of miles of line of important roads being under water, and every year it is, to a considerable extent, in different localities. It is a tolerably safe prediction that within reasonable and justifiable limits of expenditure no railway can be carried for any long distance through that place of all places for economical operation, a river valley, without being at some time and at some point under water. The conclusion that whenever this occurs it is evidence of bad engineering is not justified. There are lines in all parts of the country which are overflowed for considerable distances every three or four years for a few days, and find it cheaper to suffer the evil than to correct it. Prominent examples among innumerable others are the main line of the Pennsylvania Railroad in Trenton, N. J., various points on the Erie, Philadelphia & Erie, and Baltimore & Ohio, and various roads in the vicinity of Buffalo, N. Y.

FIG. 252.—ANNUAL RAINFALL IN INCHES AT LAKE COCHITUATE, MASS., 1852–1883.

Without going to the length of saying that this is ordinarily justifiable, which would be going too far, it is an entirely safe

statement that when the works endangered by such overflow are not of a very costly character, it is far better to risk the chances of overflow and damage at a few points every eight or ten or fifteen years, and often still more frequently, than to sacrifice the advantage of easy gradients and light first cost to avoid the risk, especially as it is often impossible to avoid it without abandoning the valley altogether. This latter has been done in not a few instances, and by no means to the advantage of the property, although of course there are many valleys which are so frequently subject to excessive floods as to make them unfit for any permanent railway line.

1055. Very great fluctuations in rainfall occur in successive years, as shown in Fig. 252, which likewise strongly indicates that there are periods of great or small rainfall of ten or fifteen years' duration. It by no means follows, however, that the years of greatest rainfall are the years of greatest floods, but rather the contrary.

CHAPTER XXIV.

THE IMPROVEMENT OF OLD LINES.

1056. It should follow from what we have already seen in respect to the errors which may be committed in the laying out of new lines, that many existing lines, built in haste and without adequate study of conditions of greatest economy, should be capable of material improvement at a cost far within the added value to the property. That this is so is a matter of common observation and belief, and many lines are already acting upon it to their great advantage. Undoubtedly the number of such lines will continue to increase, influenced by the sharp spur of necessity if nothing else, and it is probable that this would be more generally done if it were fully realized what great improvements may, in cases, be effected at very moderate cost, and how readily the possibilities in that direction may be determined without elaborate and costly surveys.

The subject is one which usually requires careful study, not so much for determining whether or not improvements can advantageously be entered on, which is often too clear for doubt, as for determining precisely HOW and WHERE the most improvement can be effected for the least money, so as to avoid the danger that, if the improvements are entered on, the expenditure will not be given the right direction, and so accomplish a part only of what might have been accomplished, or, on the other hand, will include much that was not essential and so not return interest on the capital invested.

1057. In attempting to improve an old line, as compared with a line which is still on paper only, we are at once better and worse off. On the one hand, we have a positive knowledge of its earnings, expenses, and traffic, and far more definite premises

or good reason can be shown will not be accompanied by a refusal of legal authority to make them, or by more than reasonable and actual damages. It constitutes an element to be always remembered and weighed, but not to be exaggerated without weighing it, as there is some danger that it may be.

1059. The disadvantage of having to build a line twice over is one which, while undoubted, is liable to affect the imagination far more than its real importance warrants. The constant loss from operating a bad line, on the other hand, being so gradual and continuous that it does not affect the imagination at all, the two causes may unite to indispose responsible officers to think of entering upon a policy in which the outlay is certain and seems larger than it is, while the gain is problematical, and even its possibility does not force itself upon the attention.

To construct, say, 10 per cent of a long line over again, for example, inevitably impresses the imagination as very much like adding 8 or 10 per cent to the capital invested; and as the ship is nearly sinking under the load it carries, what may happen to it with that load added? The chances are, however (Table 199 and 14), that it will not really add more than one to three per cent. On the other hand, what can seem more improbable, *a priori*, to a manager who is only hauling 25 or 30 cars per train, than that 50 or 60 cars can be drawn over the same road without, say, doubling or at least increasing one third the cost of the line? Yet this has been repeatedly accomplished, and can be again accomplished on many thousand miles of road, at far less cost.

1060. The defects which are most conspicuous in old lines which it is desired to improve are, in general, these:

1. THE PASSING BY OF LARGE TOWNS or other sources of traffic which should have been approached more nearly. This defect, although a great one in the laying out of old lines, is ordinarily not one for which alone it is expedient to change the main line, but it is often an element in considering changes which are desirable for other reasons.

2. EXCESSIVE CURVATURE; a defect which forces itself with

quite sufficient force, as a rule, upon the attention of all concerned, so that there is some danger that expenditures may be incurred in efforts to remedy this evil which might better have been given some other direction. Nothing further will be said on this subject than has been already said in Chapter VIII. on curvature; but it is beyond question that on important trunk lines large expenditures may often be usefully devoted to this, as to almost any other improvement.

3. IMPROVEMENTS IN GRADIENTS, which are generally at once the cheapest and the most important to effect, and to which this chapter will hereafter be devoted.

1061. The defects in gradients, of a remediable character, which are most likely to exist in old lines, are as follows:

1. STATIONS ON HEAVY GRADES, including as heavy grades not only those which appear heavy on the profile, but those which are sufficient to prevent starting a full train, although easily enough passed over by trains under normal headway. The number of lines is great on which several limiting stations of this kind exist on a single division, so that, as the trainmen put it, "it is harder to start the trains than to pull them up the grade." Very frequently these bad grades at stations are the only obstacles to a considerable increase of train-load.

2. GRADE-CROSSINGS of other railroads, which have often been added in great number since the original opening of the line and seriously modified the handling of trains, especially in the West.

3. NEEDLESS UNDULATIONS OF GRADE, avoidable by slight detours, and originally introduced only because the importance of low grades in comparison with a short line or cheap construction was underestimated.

4. FAILURE TO USE PUSHERS, or assistant engines: in some cases from mere oversight, but more generally because the line is ill-suited for their use without modifications elsewhere. It is unfortunately true that in the original location of most American railways this possibility has been little considered; partly because the amount of future traffic was not foreseen; partly

because the grades seemed too low to make the possibility worth considering (it being only in recent years that the use of pushers on low grades, to handle very heavy trains, has become common), and partly, in some instances, from mere lack of thought.

1062. On very many lines it has happened that there was some one short stretch on a division where a 50 or 60 ft. per mile grade was unavoidable. Grades approaching this limit were then used on other parts of the line which were easily avoidable, and can easily be taken out, from an idea (correct enough if the use of pushers is not considered) that they were of no importance if not exceeding the maximum.

Consequently, when the line was opened, trains had to be quite short. Stations were laid out or have been added from time to time, without reference to the use of any other than the short trains then handled, and new roads have from time to time put in grade-crossings, at which all trains were compelled to stop, with similar indifference to consequences, provided the new stop did not require a still shorter train than was then handled.

1063. Thus it may have come about, in the course of years, that there will be a dozen or twenty points on the division where the demand upon the power of the locomotive is almost as great as, and frequently greater than, the resistance on the maximum grade, so that no advantage, or very little advantage, would be gained by the use of pushers anywhere, and the character of the line seems fixed, without entire reconstruction. Yet the whole may be often remedied by some among the following simple ways, at very moderate aggregate cost:

1. The point or points offering most original difficulties and having, probably, the heaviest work and grades (say 60 feet) may be in some cases avoided altogether by a detour of a few miles, but in general can more advantageously be operated as it stands with a pusher, thus about doubling the possible train over it.

1064. 2. The points of next heaviest grades—there may be six or eight of them, having grades of 30, 40, and 50 to 60 feet per mile—will in some instances be so short that they are now, or can well be, operated as momentum grades, with or without

some slight modification. The feasibility of this can be determined simply and easily in the manner explained in par. 408. In other (and frequent) cases short sections of new grading will be required, to which the track complete can be removed. In some cases the regrading of considerable sections will be necessary, enabling the line perhaps to strike some new town by a detour, but endangering legal complications for damages unless both lines are maintained. Very frequently, however, such double construction may give all the advantage of a double track, for a certain distance, since the objectionable gradients may be opposed to trains going one way only.

1065. 3. The disadvantageous effects of grade-crossings may now, happily, be immediately removed in all cases by taking advantage of the laws already existing in some States (see next chapter), and to be easily obtained by effort where they do not exist, permitting such crossings to be operated by interlocking signals without requiring trains to stop at them regularly. It is now universally admitted by intelligent and well-informed men, that this is a much safer and cheaper safeguard than the stopping of trains. Exceptional crossings no doubt exist where (as some trains must stop when another happens to be passing) this remedy would not be a perfect one, and an overhead crossing preferable, especially to effect at the same time an improvement of grade, but in general dispensing with a stop by interlocking would be all that was practically necessary. The expense of doing so is considered more fully in the next chapter.

1066. 4. The unfavorable gradients at stations—very often the chief evil to be cured, although none but the trainmen may fully realize the fact—can be remedied by one or the other of numerous ways, as follows:

(*a*) By moving the station or the freight tracks only a little ahead or back, so as to reach a more favorable point; if necessary, at important stations, by completely separating the freight and passenger yard and station, and incurring some extra expense for extra operators, switchmen, etc.

(*b*) By modifying the gradients of the station, or of one or

two tracks thereat in the manner indicated in Fig. 254, viz., raising the track *a*, at the lower end of the yard, so as to give a lower grade for starting trains, at the expense of a somewhat higher grade for stopping them, the latter having no other disadvan-

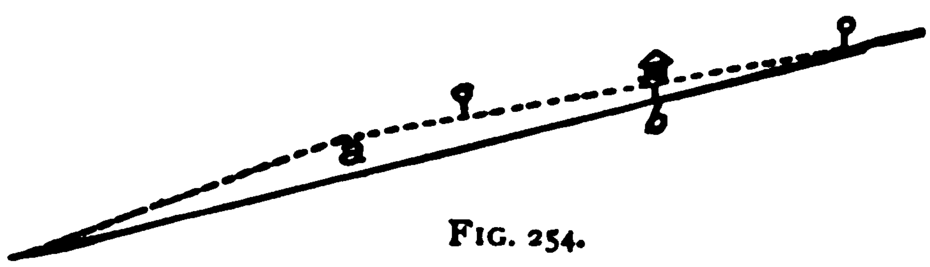

FIG. 254.

tageous effect than to check the speed of a passing train, acting in place of a brake, to some extent, if the train is to stop.

(*c*) By stationing a switchman to open certain switches, and thus saving the necessity of a train stopping at an unfavorable point to open or shut them. On large roads and at large stations this is not a difficulty, but at other points it is one which must be fully borne in mind.

1067. (*d*) By breaking through, if necessary, general rules as to which trains shall take the side track, and even (in effect if not in form) which trains shall have the right of way. The latter, of course, cannot safely be done *in form*, but the desired end can be accomplished by taking care in despatching, to have the lightly loaded trains, or those which the grades favor, held for those which cannot well stop at certain stations or only with difficulty. A general rule on this subject is commonly established and put in force over all divisions of large roads—as for instance that east-bound trains have right of way over west-bound, which latter, consequently, are by custom always obliged to take the side track at all stations, and by custom of the despatchers are commonly held so as to favor the east-bound trains. But while such a rule may work well enough on most divisions, it may work very unfavorably in others.

1068. For example, on the New York, Pennsylvania & Ohio Railroad, the general rule that east-bound trains had the right of way, which was well enough for the remainder of the road, had (and probably still has) the effect on the Mahoning Division to compel the heaviest-loaded trains to stop and take the side track,

on a curve, when half up a long maximum grade, to let trains always more lightly loaded pass down hill at full speed past them.

Such cases are not infrequent, and come to be looked upon as matters of course; but it is needless to say that they can, when occasion arises to make it expedient, be modified if necessary (1) by reversing on one division the usual rule as to which trains have right of way; (2) by giving, at some given station or stations, trains going in one direction the right to hold the main track and require an opposing train to take side track, regardless of which has right of way; (3) by favoring trains in dispatchers' orders, as before suggested.

Thus, in one way or another, it may generally be effected that trains passing in one direction past some one station on a division, at least, with unfavorable grades which cannot otherwise be remedied, shall not be compelled to stop at it.

1069. (*c*) At large stations, where there is most likely to be difficulty or great expense in adopting any of the preceding methods, a switch-engine which it is found necessary to keep at the station, but which is not kept very busy, may be utilized to help trains through the yard, and perhaps also over some unfavorable grade-crossing, which is particularly likely to come near to such a station. If the traffic of the line be very heavy this may not be possible; but in that case, as a last resort, an engine may be stationed at the yard for the sole purpose of helping trains through it. By modifying the position of the telegraph office it may in general be arranged that the use of such an engine shall cause no extra stoppage of the train. In fact, on many lines of heavy traffic, as for instance the Hudson River Division of the New York Central Railroad, pusher engines are used to help trains over short grades without stopping trains at all, the pushers coming up behind the train as it passes a switch, running two or three milles, and returning on the same track, protected by a flag.

1070. The best method of determining how much can be effected in these various ways is by observations of the variations of velocity in the handling of heavy trains on the present line in

a manner shortly to be described. In this way we eliminate the necessity of considering and allowing for a long list of doubtful elements—which throw a haze of uncertainty over any computation in which they must be separately estimated or guessed at—by simply determining by direct observation the *resultant*, so to speak, or net effect of them all. For lack of definite knowledge on a number of variable elements, it is difficult, if not impossible, either to compute or to observe, separately, either the power of the engine or the whole resistance of the train, but we can determine, very accurately and simply, the relation which the one bears to the other—which is all that really concerns us—in this way:

I. When the engine at any given point on the open road LOSES SPEED, it is proof that working with the given steam-pressure and point of cut-off it is overloaded, and the amount of velocity lost can be made a measure of how much it is overloaded (par. 400 *et al.*).

II. Conversely, if the engine GAIN SPEED at any point on the open road, under given conditions of steam-pressure and cut-off, it is a proof that it is underloaded, and the observed variations of velocity can be made to accurately indicate how much.

III. If an engine acquires speed in starting very quickly, under given conditions, without slipping the wheels or using sand, etc.; or, on the contrary,

IV. If the engine start very slowly, or not at all, without slipping the wheels or using sand, or both—the observed facts may be made a measure for accurately determining what train it could start under similar conditions with fair working efficiency.

1071. By velocity observations of the nature above indicated under varying conditions of wind, weather, temperature, long and short trains, loaded and empty cars, etc., etc. (all of which can be observed on trains by simply waiting for suitable opportunities without affecting or interfering with normal operating practices), we have a positive basis for determining from what is done under those conditions whether or not the comparative *ratio* of power to resistance on various parts of the line is seriously imperfect.

In other words, we can, by the simple observations suggested and to be described, construct a VIRTUAL PROFILE of the road under all extremes of external conditions. We can then compare these virtual profiles and determine whether or not a given set of improvements which produce a desired uniformity of resistance under one set of conditions, as fair summer weather and heavy-loaded trains, will have as great comparative value in stormy winter weather with long trains of empty cars.

POSITIVE determinations of any one of the following doubtful elements we save the need of altogether:

As respects the engine...	The ratio and amount of adhesion. The cylinder-power. The steam-power. The head resistance. The rolling-friction and friction of machinery. The gain from using sand.
As respects the cars	The rolling-friction. The wind resistance. The effect of number and load of cars.
As respects the train as a whole.............	The effect of temperature, state of rail. The extent to which momentum may be relied upon to help trains over short heavy grades.

1072. To accomplish these ends the system of observation should in detail be as follows:

The only apparatus or previous preparation necessary is a series of distance-stakes along the line, a stop-watch, and a note-book, with an observer on the engine (at times), also provided with a note-book.

The stakes are set at various governing points on the line where speed observations are desirable. They should be of a size and color to be easily visible, and should be set throughout the road at some fixed and uniform distance apart. Boards fastened to the fence may be more convenient than stakes. It is unimportant to place them with reference to mile-posts, but they should be set at top and bottom of every doubtful grade, and at the up-grade starting-point at every station and stopping-place which either is or may become in any way a difficult point, requiring consideration. It can do no harm to place them at all stations, as comparisons may be instructive.

A train moving at 10 miles per hour passes over 14.67 feet per second. As our time observations must be in seconds, it will be more

convenient to set these stakes at some multiple of 14 67 feet apart, thus making all velocity records throughout readily convertible into miles per hour from speed notes in seconds. A suitable distance is 14.667 × 20 or 293.33 feet. If set at that distance a train which passes over the distance between any two stakes in

20 seconds	is	moving	at 10	miles	per	hour.
15	"	"	" 13⅓	"	"	
13⅓	"	"	" 15	"	"	
10	"	"	" 20	"	"	
5	"	"	" 40	"	"	
A	"	"	" $\frac{200}{A}$	"	"	

In other words, *reciprocal of A seconds* × 200 = *vel. in miles per hour* between the two stakes; a very simple computation from a table of reciprocals which the following Table 201 will save the need of.

Table 201.

Speed in Miles Per Hour corresponding to the Time in Seconds in passing over a Distance of 293⅓ Feet.

Seconds.	Speed.	Seconds.	Speed.	Seconds.	Speed.	Seconds.	Speed.
3	66.7	6¼	32.0	9½	21.1	17	11.76
3¼	61.6	6½	30.8	9¾	20.5	18	11.11
3½	57.1	6¾	29.6	10	20.0	19	10.53
3¾	53.3	7	28.6	10½	19.0	20	10.00
4	50.0	7¼	27.6	11	18.2	22	9.09
4¼	47.1	7½	26.7	11½	17.4	24	8.33
4½	44.4	7¾	25.8	12	16.7	26	7.69
4¾	42.1	8	25.0	12½	16.0	28	7.14
5	40.0	8¼	24.2	13	15.4	30	6.67
5¼	38.1	8½	23.5	13½	14.8	35	5.71
5½	36.4	8¾	22.9	14	14.3	40	5.00
5¾	34.8	9	22.2	15	13.3	50	4.00
6	33.3	9¼	21.6	16	12.5	60	3.33

The disposal of the stakes at stations, where speed is slow, may be advantageously modified by putting in half-stations, so that they are only 146.67 feet apart, thus giving more accuracy to the observations; but this is unessential, and does not modify the principle.

1073. Stop-watches suitable for this purpose may be bought of any dealer for $7 to $10 each. They read to quarter or fifths of seconds, being stopped and the hands fixed at any instant by the movement of a little button. Pressure on another button, *B*, Fig. 255, restores the hand to zero, ready for another start. They are generally durable and reliable.

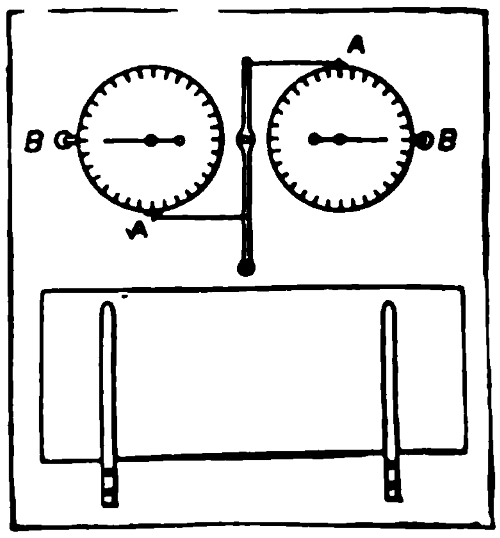

FIG. 255.

Two stop-watches may advantageously be procured and mounted together on a board, the starting buttons being connected to a single lever, as shown in Fig. 255, in such manner that a single motion of the lever will start one watch and stop the other simultaneously. This will throw the buttons for turning the hand to 0 on the outside, so that they can be readily used without danger of mistaking one for the other. It is not, however, essential that in taking a series of say five or six observations we should return the hand to zero each time. We may simply start one watch and stop the other at each station and note the actual readings, as below noted. The attachment of the lever should be so devised that there is a single point in a central position of the lever where neither watch will be started, which is a simple matter to do. A single "split-second" watch will answer the same purpose, but is more expensive.

Some brass clips, *C*, for inserting a memorandum slip near to the watches may advantageously be placed upon the board to which they are attached, and brackets or angle-plates may well be provided for readily screwing the whole firmly to the side of the car. It is convenient, although not essential, to have an observer to watch and call off the instant of passing each stake, so that the attention need not be distracted from accurately taking the time observations. A little stand or hook to carry an ordinary watch for time records may well be added.

1074. The records of a series of six or eight successive observations at any desired point may then be jotted down on the memorandum pad, to be worked up later, or on the spot, since they are likely to be needed at infrequent intervals only. It answers every useful purpose of a dynamometer record, for the fluctuations of speed are such a record.

In starting out from a station the intervals of time will be considerable, even when taking half-stations of 146.67 feet each, and there is no difficulty under any circumstances in taking readings with all essential accuracy.

1075. The simple preliminary preparations required having been made, the method of conducting the observations of the actual working of trains should be as follows:

Before beginning the more careful and accurate work a series of comparatively rude observations may well be made in which exactitude is not desired or attempted, solely for the purpose of observing the variations of velocity in the ordinary routine of service, and to learn what to expect and where to observe most carefully. No observer on the engine is needed for this purpose, and it is as well, or perhaps better, that the trainmen should know nothing of the particular purpose in view.

For the more formal and careful observations an observer on the engine is necessary; and it is desirable that the train should, in several instances at least, be run on an accelerated schedule, and that the engineman should have full liberty, and indeed express instructions, to get over the ground (and especially to pull out from stations) as rapidly as is consistent with due caution and safety; in other words, to see how quickly he can run over the division, remembering always that the cylinder tractive power of locomotive is very different at high speed and low speed (par. 557 *et seq.*).

1076. The duty of the observer on the engine is to take notes from point to point of the following details; not for the purpose of making any absolute estimates or computations, but simply to have a full record of the work of the engine:

(1) *The steam-pressure*, by record of fluctuations of the steam-gauge. It depends largely on the skill of the fireman; how much, can only be determined by trial of different men, or by their record, if on a road which has a fuel premium.

(2) *The point of cut-off*, or "notch."

(3) *The slipping of wheels and the use of sand.* The record as to the last depends very largely (par. 501) upon the skill—and even in some cases on the good-will—of the engineman. It should be remembered that he can, if he chooses, slip the wheels almost anywhere, and he will slip them, whether he wishes to or not, if he have not the requisite skill, or is not disposed to be careful. Starting is ordinarily effected by setting the valves in full gear ahead and regulating the admission of steam by the throttle. If a full pressure of steam be admitted too suddenly, slipping of the wheels is certain to ensue, even if the engine be hauling no train whatever.

1077. Too much importance must not be attached to such slipping, therefore, since it is more or less a regular incident to handling heavy trains by locomotives, which cannot be wholly avoided without cutting down trains to an uneconomical point, nor perhaps even by doing so, as is witnessed by the slipping which goes on constantly in yard work, result-

ing not from the excessive load, but from too great haste to get the load under way.

1078. The duty of the observer on the caboose (or at any other convenient point on the train) is confined to taking the time records. He should know the points at which they are to be taken very thoroughly. He should also, before starting out on the trip or after completing it, note the following details:

Number and class of engine and name of engineman and fireman.

Number and gross weight of loaded and empty cars, and whether box or flat cars, and how many ends of box cars are left exposed in the train, by being preceded by flat cars, to cause extra air resistance.

Temperature, condition of rail, and direction and velocity of the wind. The latter may well be determined by an anemometer and wind-vane on the caboose, which will give directly, what is really required, the resultant in magnitude and direction of the wind caused by the motion of the train, and that otherwise existing. With a head wind the resultant will lie in the direction of the train and have a velocity equal to the two combined; with a rear wind, it will have a velocity equal to the difference of the two, which may be zero; with a side wind equal in velocity to the speed of the train the resultant will lie at an angle of 45° therewith, and have a velocity 1.414 times greater, etc. It is not really essential that very accurate wind observations should be made, since we are not after absolute but comparative results, and it is easily estimated whether a storm or wind is or is not about as unfavorable as is often encountered.

1079. The records having been taken, the velocities at various points are taken from Table 201 and the vertical "head" in feet corresponding to that velocity taken from Table 118, in the manner which has been discussed in par. 397 *et seq.* on virtual profiles, which we are now ready to construct, preparatory to entering upon the interpretation of the observations taken. In these latter steps lie the delicate parts of the work.

CONSTRUCTION OF THE VIRTUAL PROFILE.

1080. Taking an actual profile (which need not necessarily cover the whole line, but may show only the important points; a common profile to working scales is the best), lay off at each point where time records have been taken the vertical height in feet corresponding to the velocity which the train had at that point. By an assumption which is practically correct, the average speed which a train has between any two stations is its actual

speed at a point midway between them. The vertical heights should therefore be laid off at corresponding points on the profile.

In this way we obtain our virtual profile, parts of which may be something like the dotted line on the following Fig. 256, the solid line being the actual profile.

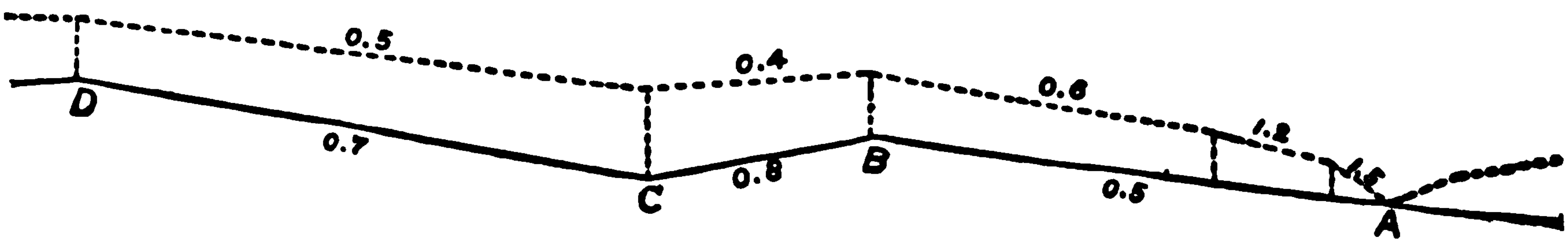

FIG. 256.

1081. This virtual profile, as we have seen, is that which alone needs to be considered. It represents a line over which, if it were actually constructed, a locomotive, exerting at every point the same energy and overcoming the same frictional resistances, would move at every point without either gaining or losing speed. On this profile what appears to be and what is coincide. If the virtual profile shows a low enough rate of grade we need not be disturbed if the actual profile below it shows a considerably higher grade. On the other hand, if the virtual profile shows a short heavy grade in pulling out from a station, which cannot be reduced by taking more time in starting trains, its disadvantage is no whit less because it is short or because the actual grade below it is almost a level.

The virtual profile will differ according to the direction the train is running, as well as more or less with each record taken; but from all these notes together a safe average is supposed to have been determined at each point.

1082. Studying how to reduce this virtual profile, we recognize three ways:

First (and simplest), TO VARY THE VELOCITY by increasing it in the hollow of grades and decreasing it on the summits and by eliminating or taking longer time for stops. By carrying this process far enough, we may reduce the virtual profile of an undulating line having very heavy grades to a level, as we have

per cent (23.8 feet per mile). This, therefore, is what we should try for over the remainder of the division. If we find it easy of accomplishment, we may consider reducing it still lower and using a heavier pusher engine, but such course is to be adopted with caution.

The actual grade at stations on this grade should not be more than 0.5 for at least 700 ft., and 1.0 for 1000 ft. beyond, but by use of sand may be somewhat higher for short distances.

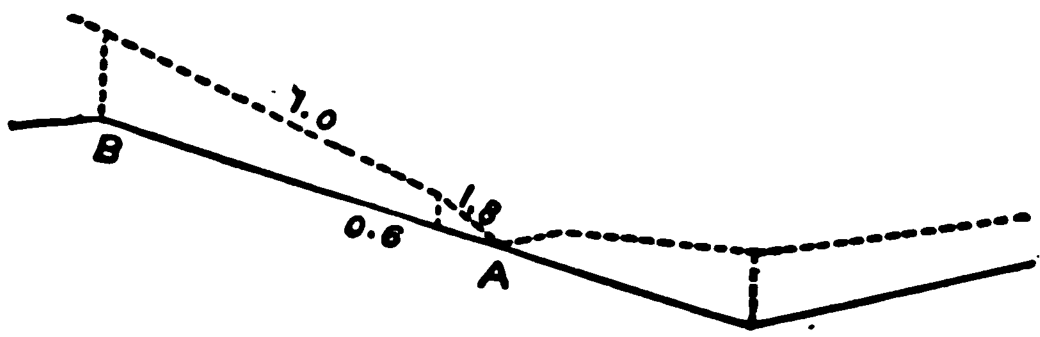

FIG. 257.

Over the remainder of the division we are liable, at various points, to have cases like the following:

1085. A station grade at *A*, Fig. 257, on an actual grade of 0.6, is operated very easily now, the train quickly getting under way even without the use of sand. By taking more time for starting heavy trains (say attaining full working speed at *B*) the virtual grade might be reduced, perhaps, to .75, but it is necessary to reduce it to 0.5 at least, and if possible to 0.4, the actual grade needing to be considerably less.

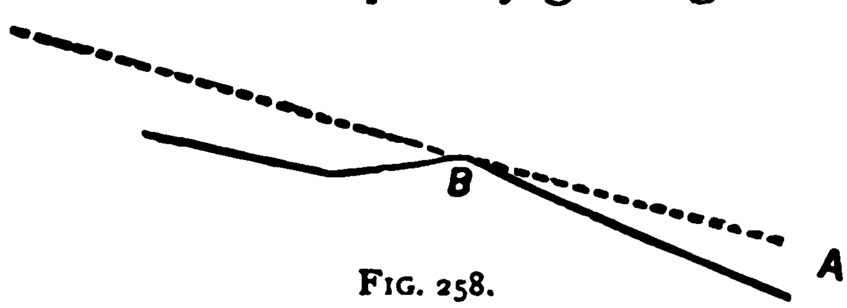

FIG. 258.

The neatest and most effectual method is to remove the station at once from *A* to *B*, this alone having the effect to favorably modify the virtual profile far more than was desired, giving that shown in Fig. 258. If this be impossible, the next best method is to take out the bad gradient in the virtual profile by raising the grade at *A* on the actual profile to *A'*, giving it the form shown in Fig. 259. Changes of this kind are apt to be expensive because of their locality; but, on the other hand, they

are inexpensive in that they are seldom very long. The effect is to substitute (in the lower half of the diagram) a broken actual but good virtual profile, in place of a good actual but bad virtual profile, as in the upper half of Fig. 259.

1086. A modification of the same case may be as follows: A station originally well situated, as S, Fig. 260, but which has been complicated by subsequent additions of grade-crossings for other lines C and C', at which all trains have to stop and start again on a grade.

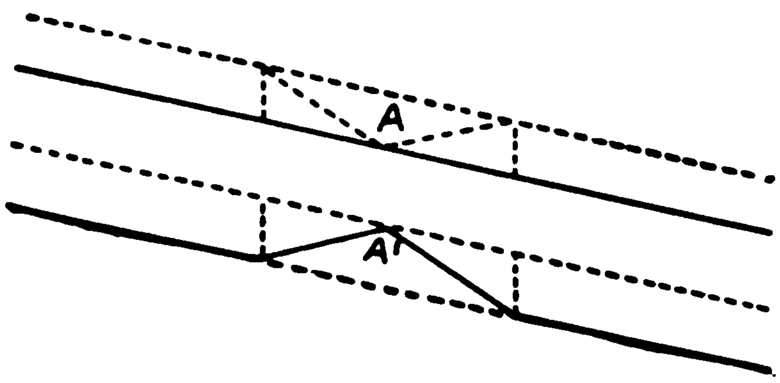

FIG. 259.

The first and best remedy for this evil is the use of interlocking signals, saving the necessity of a stop except to let another train pass; but as that is a contingency which may happen not infrequently, it can never be a perfect, nor in some cases sufficient, remedy. The evil may also, in cases, be reme-

FIG. 260.

died by raising the grade of the track approaching the crossing as outlined at C and C', provided the *virtual* grade of the approach be not increased thereby to an inadmissible rate. The only remaining course is either to use a yard engine as a helper over the crossings or to boldly lower the grade by passing under each road, and grading a new road-bed or lowering the existing one, for which room may be so scant as to require retaining-walls. This will make the improvement a costly one, and yet the cost will probably be small in proportion to the gain, unless it is only one among many costly improvements required for the desired end.

1087. At large towns it is a very common thing to find the station located at some point, like S or S', Fig. 261, which was

originally fixed more with reference to the convenience of the town than to the grades. This is of course the proper thing to do, and a decrease of station facilities, or a change causing inconvenience to the patrons of the line, will in general be inexpedient. Such large stations, moreover, are generally well provided with side tracks, so that the result is that they are largely used by train-dispatchers as passing points.

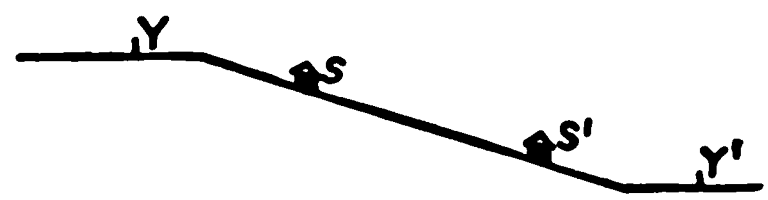

FIG. 261.

The proper remedy in such cases is to establish sidings, Y or Y', to serve as passing points for through trains only, with a separate telegraph-office, leaving the local facilities undisturbed. This requires the services of two operators to do the work of one, and perhaps one or two other otherwise needless employés, but the wages of one train crew for a single trip, it should be remembered, will pay the wages of a good operator for a week.

1088. The case sketched in Fig. 261, moreover, is one of those where the whole difficulty in handling heavier trains may be made to vanish by a modification of the system of dispatching, to the effect that only trains going down grade, or say east, shall be held at this station and compelled to take side track (except, of course, in emergencies), especially if there be another regular station near to it, as Y or Y', which may be used as a passing point, by holding one or the other train, in case it is impossible for the eastward train to reach S or S' first. It is not essential, although it is convenient, that a dispatcher should feel at liberty to hold any train, bound either way, at any station, in the regular routine of business, provided that to do so interferes with a material addition to the train-load. It is the rule and not the exception, however, that he can and does do so.

1089. The decision as to what course to adopt for modifications of gradients on the open road is a much simpler matter than at stations. The vital point to be determined in the beginning, before studying the details of the various difficult points at all, is what rate of speed is practicable and allowable at the foot

of the grade, which largely depends on the alignment. The modern tendency is very decidedly to permit of higher speed in handling freight trains, and it is essential to do so at points to handle the maximum train on all undulating gradients. The probable introduction in the near future of freight-train brakes and more mechanical coupling devices than are now in use will, when accomplished, greatly increase the admissible maximum of speed for equal safety; but even as freight equipment stands at present it is probable that 30 or 35 or even 40 miles per hour, for short distances at special points (the writer must not be understood to recommend the latter speed), are quite as safe as 50 to 65 miles per hour for passenger trains. It has been tolerably well determined (par. 664 *et al.*) that higher speeds than 15 miles per hour are more economical for freight trains; and the not uncommon feeling that any speed of over 15 or 20 miles per hour verges on the dangerous is in part a relic of the old days of iron rails, poor ballast and road-bed, and less solidly constructed rolling-stock.

1090. Therefore, when required for reducing virtual gradients by taking a "run at them," as part of a general system of improvements, a speed of 30 miles per hour (which takes 31.95 vertical feet out of the depth of a hollow; Table 118) should be freely permitted and counted on, with fair alignment; and with a tangent in the hollow of the gradients this limit may in general be safely increased to 35 miles (43.49 vertical feet), if that speed seems essential. These speeds and even higher ones are now frequently used in handling freight trains on many lines. Whatever the limit adopted, however, it should be determined in advance, by reference to the records obtained as already described, and especially with careful consideration as to whether the assumed speed *can with certainty be counted on as attainable* at the given point. Unless there be a descending gradient in the approach so as to give the required speed quickly, the high speeds mentioned cannot be counted on safely.

1091. This preliminary being determined and the present and desired gradients being the same as already assumed, viz., 1.2

actual and 0.45 desired, Figs. 262 to 265 will serve as types of all the cases which can arise on the open road. In Fig. 262 let *AB* be a long 1.0 per cent grade with curved alignment at *B* so that more than 30 miles per hour is not deemed safe at that point, but that or even higher velocity is easily attainable. With the short trains heretofore in use the grade has not been a difficult one, so that the virtual profile obtained in observations on trains as now run has been nearly parallel with the grade, the speed being lower at *B* and higher at *A* than was necessary. It is desired to determine to what extent (i.e., for what length) such a grade can be operated as a virtual 0.5 gradient.

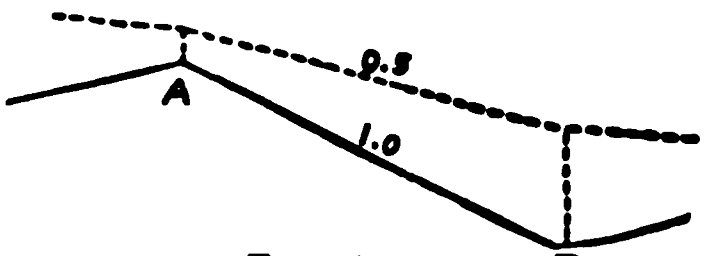

FIG. 262.

1092. A certain speed at *A*, not less than 10 miles per hour (3.55 vertical feet), must be assumed, as a margin for error, *whether there be a station at A or not* (par. 1095). Then 31.95 − 3.55 = 28.4 vertical feet, as the maximum through which momentum can be relied on to lift the train. Moreover, the actual grade 1.0 − 0.5 (assumed virtual grade) = 0.5 feet per station as the deficiency in power of the locomotive which must be made up by momentum. We have then $\frac{28.4}{0.5} = 56.8$ stations, or over a mile,

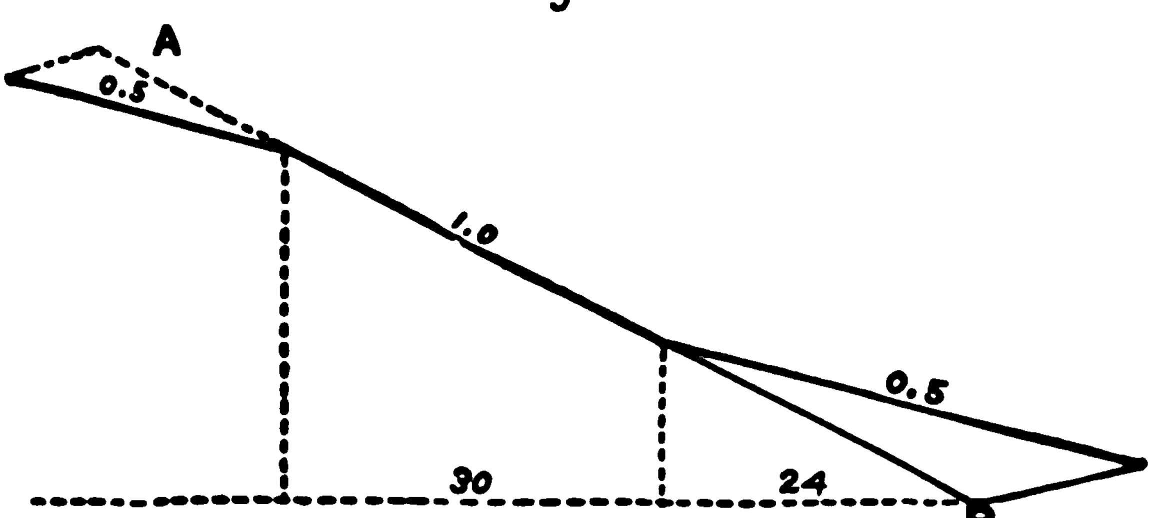

FIG. 263.

or 56.8 vertical feet of rise, as the length of this grade which it is possible to operate in this manner. If the grade be longer or shorter than this, the overplus, but the overplus only, must be taken out by new construction, either by raising the grade at *B* or (what is better) lowering it at *A*. If the grade were ten stations

longer, those ten stations, but those only, must be reduced to 0.5 actual grade in one or the other of the methods outlined in Fig. 263. If the change be made at the bottom of the hill, as at *B*, we shall have the disadvantage that on the whole of the new 0.5 gradient a speed of 30 miles per hour must be maintained to have the desired effect. As this may be or may seem objectionable, the modification may need to be more extensive to effect the desired end, and should be, wherever possible.

1093. The same is true, in less degree, of the change at the top. The train, under the assumptions, will not be able to move faster than 10 miles per hour until it has passed entirely over it. Therefore the maximum figures for the gain by momentum should be used only for determining *whether or not any modification of the grade will be required.* If it is even then found necessary, a more liberal margin should at once be adopted, if attainable at moderate increase of cost, as it generally will be.

In fact, when some construction in any case has been once found necessary it may often be best and almost as cheap to take the whole hill out at once by a detour; perhaps making the new and old lines together serve as in effect a double track.

1094. It is to be remembered in considering what allowance it is safe to make for assistance by momentum, that in many cases an error in the estimate of the possible gain from that source will have no disastrous consequences, since if it be found that the assumed speed was too great to be relied on it is possible at any time to raise the grade three to five feet in the hollow, as outlined in Fig. 264, and thus materially reduce the speed required. To do this is in most cases a comparatively simple matter, since the fills need not be very long to raise the hollow between two

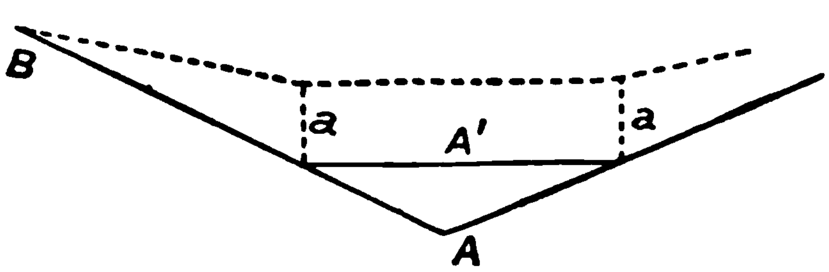

FIG. 264.

gradients by a considerable amount. If the two gradients are 1 per cent, the total length of the fill is only 200 feet per foot of lift; with 0.5 gradients, 400 feet per foot of lift; and with 1.5 gradients, 133 feet per foot of lift, etc. To make fills by train in

such locations, even if of considerable magnitude, is rarely expensive, and it can be done at any time when found convenient and essential. Therefore, when it is seen that a not excessive fill will, if made, fulfil all necessities, it is proper to rely quite largely on momentum for the time being, if by so doing the fill can be dispensed with for a time at least, and perhaps forever.

1095. On the other hand, there is a danger connected with the study of such virtual profiles, which has been alluded to above, but which should be still more explicitly pointed out. When the question whether or not we can keep within a certain virtual gradient is at stake, as in Fig. 265, it is in no case safe, even when there is a station at the top of the hill at *A*, to assume that we can arrive there with no velocity, and can consequently lay the virtual gradient directly on the actual. It seems plausible that we can do this, as we are certain that we shall need no velocity at *A*; but what we are NOT sure of is of never falling below the desired velocity at *B*, and if we do, our virtual gradient is at once increased. If we assume a certain moderate velocity at *A*, say 10 miles per hour (3.55 vertical feet), and any maximum velocity deemed reasonable at *B*, as in cases where no stop is contemplated, we are safe, because our velocity at *B* may then fall quite a little below that assumed without endangering our arriving at *A* with some velocity, so as to float the train over it; but if we assume we are to arrive at *A* with no velocity, simply because the train must stop there, we are liable not to reach there at all. No advantage can be assumed, therefore, from the fact of a stop at the top of the gradient more than would exist if there were to be no stop there at all. In either case we must be sure of reaching the top, and in neither case is it important to be sure of more than that.

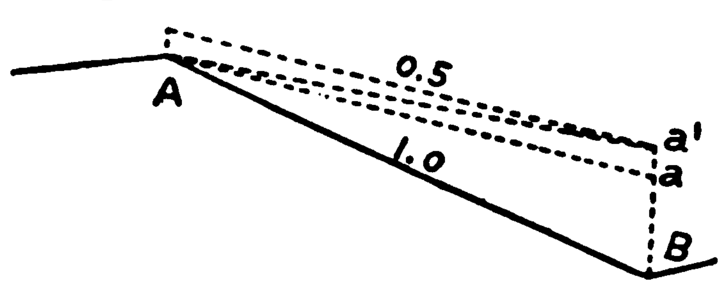

FIG. 265.

1096. The temptation may be great to fall into this plausible error, when an estimate, perhaps, must be kept very close to have the work go through at all, and when there may be an expensive

bridge at *B*, making it difficult to lift up the grade at that point; but if a reasonable velocity at *B* and some velocity at *A* will not suffice, there is nothing for it but either to raise the bridge, lower the station, increase the distance between them, or give up the desired virtual maximum as unattainable.

1097. By attacking the work of improving old lines in the method here outlined, halving the more formidable and inevitable grades at once by using a pusher on them, without spending a dollar on them, and spending all our money on what were before the very easy grades, and hence are usually in light work, the average train-load may be doubled at small cost on thousands of miles in this country; whereas by merely attacking the heaviest grades which show on the profile with force and arms, so to speak, a great deal of money must be spent, and there will be comparatively little to show for it.

CHAPTER XXV.

GRADE-CROSSINGS AND INTERLOCKING.

1098. THE multiplication of grade-crossings has become a great and serious question, especially in the West. The topographical conditions in the East greatly restrict the danger from such crossings, as well as their frequency; but throughout vast regions of the West there is absolutely nothing to prevent a railway being built from anywhere to anywhere in very nearly an air-line by accepting "moderate" grades of 40 to 80 ft. per mile. As a consequence, many important lines have little or no assurance that crossings may not be demanded of them sooner or later on any single mile of their track, and it becomes of great importance to determine how strenuously they should oppose such crossings, what expense they may and should incur to avoid them, and what can be done to reduce their disadvantages to a minimum when unavoidable.

The problem has been greatly simplified in recent years by the fact that the disadvantages of grade-crossings may be largely diminished, and sometimes almost destroyed, by the use of interlocking apparatus, as we have seen in par. 1086 and elsewhere; but while there were in 1885 some 60 railways in the United States using interlocking more or less, the total amount in use was considerably less than on the London & Northwestern alone.

1099. There are 18 different sizes of standard signal-cabins on the London & Northwestern Railway, which are:

A. 5 levers, 6×6 ft.		D. 20 levers, 16 ft. $2\frac{1}{2}$ in. $\times$ 12 ft.
B. 10 " 9×9 ft.		(and so on to—)
C. 15 " $13\frac{1}{2} \times 12$ ft.		T. 180 levers, 96 ft. 6 in. $\times$ 12 ft.

The usual rule being that the cabins are all 12 ft. wide and are 6 in. long per lever, plus about $6\frac{1}{2}$ ft. There are 1344 of these cabins on 1753 miles of road,

containing 26,500 levers. The annual average cost for maintenance is $187,000, which, divided by the number of levers in use on the line, comes to $7.07 per lever. This amount includes not only the renewal and repairs of the locking apparatus, but that of the signal-cabins, signals, and all subsidiary apparatus, and also the cost of providing any new and additional apparatus, when under $50. The amount of work to be maintained has increased 80 per cent since the year 1874, while the cost of maintenance has only increased 5½ per cent.

In the whole United States there are, of all systems (1885), somewhat less than 250 cabins and 3000 levers, or but about one fifth as many cabins and about one ninth as many levers as are in use on the London & Northwestern alone.

1100. In England there are practically no grade-crossings of railways, and this apparatus is used chiefly for yards and junctions. In America there are a great many grade-crossings, even on important lines; but the clumsy and costly precaution of a full stop of every train at every crossing is still the rule, although it can hardly be that such an absurd relic of barbarism will linger much longer, now that there is a considerable and increasing number of grade-crossings operated without a stop by the aid of interlocking apparatus, and always with perfect safety and success.

1101. In part, the slow progress in this matter is easily explained. The great loss and delay from grade-crossing stops goes on quietly and silently, sapping the life-blood of the company, as do the consequences of bad location (page 2), without interfering much with the routine of operation, and at points removed from the managing officers' immediate observation, whereas the difficulties at yards obtrude themselves on attention, and many of the most crowded yards have passed the limit of their capacity without some such mechanical aid.

1102. Nevertheless, from an economical point of view, abolishing the stop at grade-crossings is by far the most important, especially when, as is so frequently the case, they reduce the number of cars hauled below what it otherwise would be. To reach this conclusion we need not adopt any of the wild estimates which give the cost of a stop at anywhere from a dollar up. Without going elaborately into the details of the estimate, to discuss which properly by items would take considerable space,

from 30 to 60 cents may fairly be taken as the cost of a stop, apart from all effect on length of trains. An estimate of 40 cts. per stop for average trains on lines doing considerable through business can hardly be considered excessive, and at this rate the cost per year of each train per day stopping at the crossings is $365 \times 40 = \$146$ per year. If therefore there is an average of ten trains per day each way for each of the roads which cross (and the average at grade-crossings would probably be more rather than less than this), we have $\$146 \times 10 \times 2 \times 2 = \$5840$ as the annual loss to both roads from the fact of the existence of this crossing.

1103. The cost of saving this loss by constructing a new line or by interlocking, will vary more or less with the locality and in less degree with the system of interlocking adopted; but the variation in the latter respect is not important, and the outside limit for a complete system of interlocking switches and signals for either single or double track (it makes little difference which), by one system of approved excellence may be stated to be from \$2500 to \$4000, averaging \$3000. This includes eight signals (four "home" or near signals, and four distant signals, two for each track), four derailing switches, one for each track, which throw the train off onto a graded road-bed (having no rails and ties for only a short way), if the signal be carelessly run by, and (for a separate sum of \$400), electric locking apparatus which renders it impossible to change the signals after a train has once passed the first distant signal until it is over the crossing. The cost of the building and of erection is included in the above.

One man only is required to attend to the signals, as is required without interlocking, and his wages need be little if any higher, so that this item may be considered unaffected.

1104. Even with the lightest ordinary traffic, therefore, the lowest reasonable estimated cost of stop, and the highest probable rate of interest, THE SUM SAVED ANNUALLY *is far more than enough to cover the additional expense of thoroughly protecting a grade-crossing so that no stop need be made,* without considering the

greater safety and convenience. At more important crossings it would be hard to find a clearer case of an expedient improvement, even if the stops do not cut down the length of train.

1105. If the length of train is cut down, so as to take, say, 21 instead of 20 trains per day to handle the traffic, the very lowest cost for which the extra train can be run is (Table 176) 35 to 40 cents per train-mile (for an average cost of 70 to 80 cents), or say $38 for a trip of 100 miles, amounting to $13,870 per annum, or $693.50 for each of the 20 trains, or $1.90 per stop (if only one stop causes the decrease of train-load) IN ADDITION TO THE DIRECT COST of the stop. In such cases, of which there are many, it is culpable folly to delay availing one's self of so cheap and easy a remedy for such losses as interlocking affords, if the conditions are not favorable for the still better and in the end often cheaper remedy, an over- or under-crossing.

1106. A fact which explains rather than excuses the prevailing negligence in this matter is this,—that the protection of grade-crossings requires the joint action of two roads, usually under different and often under antagonistic management, and it requires no little negotiation, and a conciliatory spirit on both sides, to arrange the details of the distribution of the expense.

It can hardly be doubted that this difficulty is a serious one, and it is largely the fault of the laws which authorize the use of interlocking as a substitute for stops. By some singular oversight, all these laws as yet passed (1886) authorize roads to "agree" on putting in interlocking, but do not provide a way by which one road, anxious to act under the law, can compel another road to accept a reasonable settlement by arbitration or otherwise, unless it chooses to.

1107. The provisions of the State laws as to dispensing with crossing stops may be briefly summarized as follows :

The MASSACHUSETTS law passed in 1882, after somewhat urgent recommendations by its Commission, which were at the time regarded by many as somewhat heretical (because the public knowledge of interlocking was much less then than it is now, even among railroad men), provides that "The approval of the Board shall be required for a system of signals to be established and maintained in concert" by railroads which cross each other, but that a full stop shall

not be dispensed with "unless a system of interlocking or of automatic signals, approved in writing by the Board, *is adopted by both corporations.*"

OHIO, at almost the same time, provided by law that "any works or fixtures" approved by the Commissioner of Railroads and Telegraphs as rendering it safe to dispense with stops, plans having been filed with him, shall dispense with the necessity of a stop; and if the Commissioner shall fail to approve the plan within twenty days, "*such companies*" may apply to the Court of Common Pleas, where appropriate action will be held. This enactment seems to require not only that both companies shall consent passively, but that they shall unite in active legal proceedings to avert a decision which might be not unwelcome to one of them.

MICHIGAN (1883) passed first a very absurd enactment that "authority is hereby given to said Commissioner, and it shall be his duty, if he shall deem it practicable, to prescribe the use of the interlocking switch and signal system, provided that at crossings where all trains come to a full stop no other system than that requiring such stop shall be prescribed."

The absurdity of thus cutting off one of the chief advantages of interlocking signals struck the Legislature almost immediately, however, and another act of the same session provided that "whenever there shall be adopted and used at any such crossing an interlocking switch and signal system, or other device," which the Commissioner thinks makes it safe to dispense with a stop, he may authorize it in writing, with any regulations as to speed or other matters which he deems necessary, and with power to revoke his action.

In the strict letter of these laws, the Commissioner may prescribe automatic signals without dispensing with a stop, but can only authorize the stop after the apparatus is adopted and in use. Neither is he—what is a more serious matter —given any specific power to say what part of the expense each of the two companies concerned shall bear. These provisions come the nearest, however, of those of any State to providing means by which one railway which is anxious to escape from the burden of stopping at a crossing can compel the other beneficiary to bear its fair share of the cost.

The INDIANA law (1883) is merely permissive, authorizing the Auditor of State to approve interlocking or automatic signals at crossings, from plans submitted by "*two or more* railroads," which have erected or are about to erect them, and thereafter to authorize the omission of stops. It is specifically provided that such signals shall not be "used or put in" at any crossing "to the detriment of any other railroad company," unless with the consent of that company in writing. Under this provision, the manager who wishes to dispense with twenty different crossings must first undertake the interesting task of persuading twenty different companies that it will not be "to their detriment" to do so.

The NEW YORK law (1884) provides that the requirement of a full stop may be dispensed with whenever the Board of Commissioners "decide it to be

impracticable" or where "interlocking switch and signal apparatus is adopted and put in use by the railroads there crossing each other at a level," of a form approved by the Board.

ILLINOIS passed through one house in 1886 an act essentially similar to that of New York, which was expected to become a law at the following session.

1108. It is easy to see how, under any of these laws, a manager attempting in good faith to benefit his company and benefit the roads crossing and the public as well, by perfectly fair and equitable arrangements for dispensing with stops at crossings, might find it an irritating and almost hopeless task, and might feel compelled to give it all up in disgust before he had fairly begun.

The difficulty of agreement is precisely the same as would exist in cities as respects party-walls, without the law which authorizes any man to build half his wall on his neighbor's land and compel his neighbor to pay for it when he uses it. The equities, and the great advantage to both sides, are here exceedingly clear, yet how often would it be impossible to arrange the matter if it could only be done by mutual consent and agreement in each case?

The case is worse with crossings because they are very frequently so situated that the joint consent of three or four lines is necessary for any action, and in still more instances a great part of the advantage to be realized from dispensing with any one crossing can only be obtained by dispensing with a series of perhaps a dozen.

1109. To require that grade-crossings should never be permitted would unquestionably be going too far, especially now that interlocking apparatus has been invented and perfected; but the unrestricted freedom with which, in most of the States, grade-crossings can be forced over any line at almost any point, regardless of the injury inflicted, is an unfortunate and shameful state of things, which pressingly requires correction, and which perhaps might readily be corrected if the older and more important railways would make a united effort to secure reasonable and proper restrictions. Unfortunately they overreach themselves by asking far too much.

1110. The theory of the present laws is a very simple one; something like this:

1. "Railways are a supreme public necessity, and no private interest or ownership shall be allowed to stand in the way of their cheap and easy construction.

2. "When two railways want the same spot of ground they shall occupy it in common."

Unfortunately, like most short and easy cuts to justice, it is unequal and unfair in practice.

The theory of the great existing railways is equally simple, and would, if it were allowed to prevail in practice, be equally unfair:

1. "Our railway is a much greater public benefit than these other new projects, and we have bought and paid for our property.

2. "If they want to pass over our property they must keep out of our way."

1111. This preposterous attitude—from corporations whose very existence was made possible only by the exercise of the supreme power of the State, and whose very nature is to perform one of the duties of the State to the public—is all but universally assumed by established corporations in discussions of crossing cases; except in those cases when they wish to build branches or sidings over a rival's road. They are very quick to point out that some new line can build an over-crossing for less money than they lose by a grade-crossing, but they rarely offer to pay a reasonable proportion of the extra cost of the course they desire. Even when they do so, there being no recognized tribunal to decide the matter, they will higgle and chaffer over the amount to be paid till the whole negotiation goes for naught.

1112. The solution of the whole matter seems comparatively simple. The law very properly takes the position that mere priority of construction shall be allowed little or no weight. All railways alike are supposed to be of pressing necessity to a certain number of people—many or few, as the case may be; and the necessities of even a very few are given greater weight than a loss and inconvenience which is comparatively trifling to each individual affected, and can only become very large when distributed among a large number of people. This is right and proper as far as it goes, but the law should also take this further precaution: without paying any attention to the vested interests concerned, as such, it should endeavor to enforce that course which is *for the best interest of the community as a whole*, and which

involves the least aggregate waste of human labor and property; and it should endeavor to distribute the cost of so doing as nearly as may be in proportion to benefits derived, and in such manner that each party shall be benefited, by taking what is abstractly the proper course. All this might be obtained by something like the following simple provisions:

1113. 1. Every railway hereafter attempting to cross another at grade shall be obliged to erect and pay for a system of interlocking signals, to be thereafter maintained at the joint expense of the two roads, unless it shall appear that less than twenty trains per day pass the crossing.

2. Any railway may at any time erect interlocking apparatus at any grade-crossing, and half the cost of erection and subsequent maintenance shall be chargeable to the other party concerned, with certain provisions for exceptional cases; and also provided—

3. Either party wishing to avoid a grade crossing should be at liberty to locate an over- or under-crossing on unobjectionable gradients, and to demand the appointment of arbitrators in the usual manner. It should be the duty of these arbitrators, *first*, to determine that the grades and alignment of the new line are of a suitable and appropriate character, or to make them such; *secondly*, to determine the excess in cost, if any, of the over-crossing over the grade-crossing; and, *thirdly*, to assess this difference in cost upon the two lines in proportion to the benefit to each of avoiding a grade-crossing.

1114. These three provisions seem calculated to accomplish what every good law ought to accomplish. They would make it for the interest of both parties to take that course which would be best for their joint interest, if they were one corporation. Thus, supposing a new road which will run say five trains a day wishes to cross a trunk line running 50 trains a day. The actual loss to the community of a grade-crossing at such a place is the cost of stopping 55 trains a day, and no one has a right to enforce such a loss upon others to save an investment of a few thousand dollars. On the other hand, if the new project wanted

to cross another minor line like itself, running, say, five trains a day, neither road would be likely to move for an over-crossing, nor perhaps even for interlocking signals; nor is it for the interest of the community, considered as a whole, that they should do so. It is not true at all that every element of danger must be wholly eliminated before any saving of expense, however great, is permissible, but that methods which are at once more dangerous and more costly should have continued in such wide and all but universal use so long will seem in later years a strange comment on our civilization.

CHAPTER XXVI.

TERMINALS.

1115. TERMINAL facilities, or the lack of them, have so many times been a leading factor in the success or failure of railways, and are in all cases so important a factor, that it seems desirable to show more fully than has been yet done how great a part they are of the investment in and the expenses of prosperous lines, and hence how dangerous it is for a new line to neglect ample provisions for them. This perhaps can be best accomplished in a small space by presenting some details as to the terminal facilities at a few great traffic points.

1116. Table 202 gives an unofficial approximate estimate, compiled by Gratz Mordecai, C.E., of the actual capital represented in the terminal work of moving and handling freight by the trunk-line railroads at the port of New York. It includes the work of handling coal on the Delaware, Lackawanna & Western Railroad, but on no other, and only includes a small part of the expenses of handling and lighterage of grain, oil, and live-stock, and none of the expenses of clerical work and management on any of the roads. It may be summarized thus:

Estimated Cost of New York Terminal Facilities.

		Capital sum, millions.	Cost per year.	P. C. of total.
200 miles track	@ $10,000	2.0	0.12	2.2
378 acres yards	@ 52,000	20.0		
2.2 millions sq. ft. piers	@ 1.00	2.2		
2.0 millions sq. ft. floor area	@ 0.80	1.6		
0.89 millions sq. ft. N. Y. city stations	@ 6.00	5.4		
69 yard engines (cost)	@ 8,700	0.6		
44 propellers (cost)	@ 25,000	1.1		
230 lighters (cost)	@ 9,000	2.1		
Total investment charges		35.0	2.1	38.5
4,700 employés	@ $2 per day	47.0	2.82	51.6
450 tons coal per day	@ $4,	9.0	0.54	9.9
Total		91.0	5.46	100.0

TABLE 202.

TABULAR SUMMARY OF RAILWAY TERMINAL FACILITIES AT NEW YORK.

[Compiled by Gratz Mordecai, C.E. The table does not claim to be precise, and probably errs by omissions.]

NAME OF ROAD.	FIXED PLANT.						LOCOMOTIVE.			POWER.	
	Total Track in all Yards.	Termini on Hudson River.				New York City Stations, covered Floor Area.	Yard Engines.	Propellers.	Lighters.	Average Laborers, etc., employed Daily at Yards, etc.	Average Coal used Daily.
		Track in Yards.	Area of Yard ex. of Piers.	Area of Piers.	Covered Floor Area.						
	Miles.	Miles.	Acres.	Sq. ft.	Sq. ft.	Sq. ft.	No.	No.	No.	No.	Tons.
N. Y. C. & H. R. R.	28	28	83	450.000	350,000	350,000	14	12	40	1,300	110
Pennsylvania R. R.	39	20	71	300,000	360,000	290,000	15	16	80	1,300	120
N.Y., L.E.&W.R.R.	49	30	70	250,000	300,000	150,000	16	8	55	1,000	100
D., L. & W. R. R...	50	44	74	600,000	*a*540,000	*b*	15	*b*..	*b*..	*b*300	*b*50
N.Y., W.S.& B.Ry. / N.Y., O. & W.Ry.	34	12	80	*c*600,000	450,000	100,000	*d*9	8	55	800	70
Total..........	200	134	378	2,200,000	*e*2,000,000	890,000	69	44	230	4,700	450
Cost per unit, dollars	10,000	....	52,000	1.00	0.80	*f*6.00	8,700	25,000	9,000	2.00	4.00
Representing millions of dollars capital.........	2.000	....	*g*20.000	2.200	1.600	5.400	0.600	1.100	2.100	(@6 p.c.) 47.000	(@6 p.c.) 9.000

a. Includes coal-trestles.

b. None of the expenses of handling and lighterage of miscellaneous freight on this road is included, as that work is done by contract.

c. Proposed total, 1,500,000 sq. ft.

d. Most of the freight on these roads comes in large lots, hence there is less sorting of cars required in the yards than would be required otherwise.

e. Includes area of both first and second floors, but not the track room.

f. Includes both land and structures.

g. Includes land, grading, etc., at all yards and stations, except in the city proper.

The only direct return received from the merchants by these railways for this work, the plant of which represents an aggregate capital of at least $35,000,000, and the power and force employed an annual expenditure of at least $3,500,000, are the charges collected for long-distance lighterage. There is, however, a considerable fixed terminal charge of five cents per cwt., more or less, which is credited to the terminal road before the division of rates is made according to distance (par. 210), so that the roads terminating at New York are, perhaps, less burdened than the average by the terminal expenses. Assuming 6 per cent interest, this estimate shows a total annual expense of $5,500,000, and taking into account clerk hire, management, repairs, taxes, light, stationery, insurance, and all other expenses, the total is probably not far from $10,000,000, or an average burden on each road of $2,000,000 every year.

1117. If we include the terminal expenses paid by the individual shippers, as well as by the railways, the above totals, large as they are, sink into insignificance. It was estimated in 1875 by a committee of the American Society of Civil Engineers that on some 4,632,000 tons of the freight delivered at New York the total terminal expenses were $3.07 per ton, or about three fifths of the then rate (25 cts. per 100 lbs.) from Chicago to New York. The total receipts at New York in that year were about 15,000,000 tons of all kinds of freight, and on half of this the cartage charge alone was estimated at $1.60 per ton.

Inasmuch as so much more for cartage means so much less available for freight rates, and *vice versa*, on a large proportion of the freight, and more or less so on all of it (par. 47), we have in these figures some indication of how serious a deduction the total terminal expenses must make from the amount available for railroad transportation proper, and how important it is to have terminal facilities of the best. New York, however, is a true terminal, in the strict sense of the word. Some of the terminal points, which are really only yards of interchange, are of even greater magnitude, if not cost. Lest the great error be fallen into of assuming that the terminal facilities at New York are as much greater than those at other cities, as New York is

TABLE 203.

MILES OF TRACK IN THE YARDS OF BUFFALO, N. Y., OCTOBER, 1884, WITH THE PURPOSE FOR WHICH IT IS USED

S, Single main track. D, double main track. (For miles of line, divide double track by two.)

MILES OF TRACK WHEN CONTEMPLATED IMPROVEMENTS ARE COMPLETED.

This table was made in October, 1884; since then the Rochester & Pittsburg, the New York, Lackawanna & Western, and the Lehigh Valley have each laid several miles of track. The change of ownership of the West Shore road will stop the construction of about 50 miles of track on that line.

The Buffalo Creek is a junction railway, running around the city and really a part of the terminal facilities merely, in its entirety.

greater in population, some notes may be added as to what is really only the largest of many examples of interior yards—those at Buffalo, N. Y. So far from there being anything exceptional in the New York terminals, they are probably smaller in extent and cost per head of population than at most important terminals, and vastly smaller than at a number of them.

1118. The statistics presented in Table 203 of the yards in Buffalo leave no reasonable doubt that, of its kind, it is the greatest in the world. How much of this abnormal magnitude is the healthy and natural result of peculiar traffic conditions, and how much of it is mere fungous growth from diseases of management whose existence is universally felt, it would be useless to inquire here, because as things are it is all necessary, and there is no immediate evidence of any probable change. The headings to Table 203, in which fourteen different kinds of side tracks are specified, will at once explain in part why so much of some of them is necessary. In the aggregate there is a total of some 300 miles of side track within an area of some eight square miles (about $1\frac{1}{2}$ by $5\frac{1}{2}$ miles, 5.63 square miles being actually owned by the railways within the city limits), which it is expected to increase in the near future to some 450 to 500 miles, mostly by accessions to the trackage of the newer lines entering Buffalo, and required by them—as will be seen by the detailed table—to afford to them no greater facilities than the older lines already enjoy. The lease of the West Shore to the New York Central saved, it is estimated (somewhat liberally, it would appear), the construction of as much as 50 miles of track which would otherwise have been necessary, but, barring that, there is—

	Miles. Single track.	
Tracks of all kinds in city limits of Buffalo or immediately adjacent thereto	436.1	
And to be laid by the new roads (chiefly) now imperfectly supplied	176.0	612.1
Of this there is *main track*, including three double-track lines swinging around the city to a connection with the International Bridge	155.1	
And projected (minor extensions)	5.7	160.8
Leaving as side track		451.3

Of the main track a considerable portion is only nominally main track, but really more in the nature of track for yard use only, which may be estimated as at least	50.0	50.0
	(Main.)	(Side.)
Leaving as the true proportions of main track and side track, actual and projected	110.8	501.3
Of which there was laid, October, 1884	109.3	326.8
And projected, a considerable fraction of which has since been constructed	1.5	174.5

1119. If we compare this with the figures for the yards of New York City, as given in Table 202, we shall have a better idea of the magnitude of the Buffalo yards. The total miles of track, main line and sidings, at the two points compare as follows:

	New York yards.	Buffalo yards.
New York Central	28	157
Erie	49	116
Lackawanna	50	63
West Shore (and Ont. & West.)	34	23
Pennsylvania	39	..
Other roads	..	77
Total	200	436

It will be seen that, with all the immense traffic of New York, there is less than half as much track at New York as at Buffalo. In the yards of Boston there are 150 miles of side track, on 568 acres, with 26 acres of buildings; the total side track on all the nine roads centring there being 765 miles for a total of 814 miles of main line.

1120. The New York tracks are also different from those at Buffalo in not being all bunched together, so as to be in fact, if not in form, one vast yard, whose different parts are constantly interchanging business with each other. The New York yards are miles apart from each other, and have comparatively the most insignificant interchange relations. Most of them, in fact, could be most fairly compared with the thirteenth class of Buffalo side tracks, those for "local city freight" alone, of which there are in Buffalo 20¾ miles, with as much more projected; for, although there is a very large—in fact immense—coal, steamer, and stock-yard traffic at New York, as well as the usual shop

and coaling tracks, yet the business of New York is carried on under such different conditions from that at Buffalo that the same traffic requires, as is apparent from the figures, several times less track room. For example, there are 39 miles of shop and coaling track at Buffalo, and 35 miles more projected, of which the New York Central and the Erie have each some 13 miles, which (without being able to present the exact figures) is undoubtedly several times greater than the same roads have for the same purposes at New York, the reason being that sick and wounded cars from all over the continent tend to accumulate at Buffalo, while they are kept away from New York so far as possible. The same contrast is visible in the 16 miles of transfer tracks at Buffalo, which it is proposed to double; and the enormous aggregate of 87 miles for the direct use of trains from the East and West and Canada, and for distributing West-bound freight (columns 3, 4, 5, 6, 7, Table 203), to which it is proposed to add over 40 miles more, mostly by the newer roads, is in itself something for which there is no very exact parallel in New York, either in quantity or quality, although, of course, the mileage devoted to similar uses is very great.

1121. The same contrast exists to an even larger extent in the areas of land occupied in the two cities, which compare as follows:

In New York, land	378 acres.
piers	5 "
	383 acres.
In Buffalo, land	3,600 acres.

Land in Buffalo is, of course, a very different and much cheaper thing than land in New York, and this area, moreover, includes several hundred acres of what is more properly main-line right of way, not properly chargeable to yards. But after making all allowances in this respect, the immense proportionate magnitude of the Buffalo yard, due to the nature rather than to the absolute volume of the business transacted, which makes Buffalo a point where innumerable side tracks naturally accumulate, is clearly indicated.

1122. While Buffalo seems to be far ahead of any other one point in its yard facilities proper, yet that it is only the leading example of a general tendency may be indicated by the figures given in Table 204 of the total side-track mileage of the roads entering there, which well illustrate the immense aggregates of side track which even ordinary yard demands produce. There seems to be what might almost be called a rude law, that trunk lines proper, as distinguished from roads of the next grade below, will have at least as much side track as the length of their main line. Thus, the Boston & Albany, in addition to being somewhat more than double-tracked, has almost exactly this amount of sidings, viz., 203.2 miles against 201.6 miles of main line. Exceptions, no doubt, exist; but Table 204 indicates that the assumed "law" has at least some foundation in fact.

TABLE **204.**

MILEAGE OF SIDINGS IN THE AGGREGATE AND AT BUFFALO AND NEW YORK, ON THE LEADING LINES ENTERING BUFFALO.

ROAD.	Miles Main Line.	MILES OF SIDINGS.				Per Cent of all Sidings in Buffalo.
		Buffalo.	N. Y.	Elsewhere.	Total.	
New York Central...	442	94.1	28.0	418.9	541.0	17.4
Lake Shore..........	540	9.3	....	539.7	549.0	16.9
Total...........	982	103.4	....	958.6	1,090.0	9.5
Erie................	460	77.2	49.0	430.8	557.0	13.9
Lackawanna........	413	30.8*	50.0	442.2	523.0	....
B., N. Y. & P.......	430	19.0*	....	129.0	148.0	....
Rochester & Pittsb'g.	213	4.9*	....	48.1	53.0	....
West Shore.........	426	16.3*	34.0	91.7	142.0	....
N. Y., C. & St. L....	512	3.5*	....	85.5	89.0	....

* These roads have completed less than one half of their proposed Buffalo sidings.

The immense aggregate of capital expenditure represented by these aggregates of side track, and the still larger capital sum represented by the annual expenditure to "operate" the side tracks, are plainly factors in the future of new and old lines which can never be safely forgotten.

1123. It is estimated that fifteen miles alone of the local tracks at Buffalo have cost, or would cost to replace, $350,000 per mile, or $5,250,000, this particular fraction of the local trackage being, as is often necessary, on exceptionally expensive land, where it is readily salable at $300 to $500 per foot front. The railways own strips varying from 60 to 100 ft. deep, and on them are laid three to five tracks, giving the following estimate for four miles of track:

5280 ft. of land at $250 per front foot	$1,320,000
Planking, 60 × 5280 ft. × 3 in. = 1050 M. ft., or with sub-sills 1200 M. ft. at 18 cts	21,600
Grading, averaging 3 ft. deep at 25 cts. per cu. yd	11,750
4 miles of track at $6000	24,000
Total	$1,377,350
Per mile of track	344,340
Add for approaches of paved streets, paving many of the tracks themselves, and incidentals	5,660
Total per mile	$350,000

We need not attempt the difficult task of estimating the total exactly, but for the other items: At $10,000 per mile the 300 miles of side track, more or less, in the Buffalo yards represent $3,000,000. At $5000 per acre for the 3600 acres of land owned and used for railway purposes, the capital investment would be $18,000,000. The shop facilities alone, with the tracks for their use, represent $3,000,000. Vast as these sums appear and are, the interest on them represents but a small part of the addition to the cost of haulage which the terminal facilities cause, and still less is the bare trackage required any fair criterion. This will be clearly indicated by referring back to Table 202, where it will be seen that at New York the bare cost of the track, estimated at a very liberal figure, and exclusive of land, amounts to but 2.2 per cent of the total cost of yard work, and that this total is as great a tax upon the five lines concerned as if they had $91,000,000 invested, say in three thousand miles of idle, unoperated, and tolerably costly railroad, at $30,333 per mile, on which they had to pay interest, but which contributed nothing to revenue.

1124. Nothing equal to this in degree exists in Buffalo, but the analogous tax at that point is very great indeed, and is *in addition* to the New York tax, as is likewise the yard tax at Chicago, and all other intermediate points. Therefore, vast as is the tax of maintaining within the city limits of Buffalo enough track for local purposes only to build a new line to New York, that direct expenditure is but a small part of the total burden represented by those facilities, even if a many times larger part than at New York, as no doubt it is.

At no other point in this country, not even at Chicago, do so many conditions combine to bring about such abnormal growth, and the same is still more true of even the largest cities of the old world. Buffalo, therefore, although outdone by many other cities as a traffic point, will doubtless continue to be the greatest yard, properly so called, in the world, even after that considerable fraction of its trackage, which is with reason felt to be due to profligate and discreditable imperfections of management, has been done away with. But its interest for our immediate purpose lies in the fact that, large as it is, it is only the largest outgrowth of universal tendencies; and that road which attempts to compete with another without having approximate equality in such terminal facilities, competes on about as favorable terms as it would in crossing a river by some new bridge in which every span but the last had been built, and was of very superior quality.

Much greater sums have been spent in Europe than here in building stations in the trade centres of cities close to the warehouses and wholesale stores. In Liverpool (600,000 inhabitants), the London & Northwestern Railway up to 1881 had expended $9,300,000 in providing freight stations alone. In London it had expended $11,200,000. Interest at the rate of 4 per cent on the cost of these stations, less rents received for warehouses, etc., amounted at Liverpool to 14.6 cents, and at London to 32 cents per ton of freight handled. Thus the mere payment of interest on the terminal facilities, excluding any charge for handling the freight, would, on a haul from Liverpool to London, amount to 46.6 cents per ton, or nearly ¼ cent per ton-mile. These figures do not include the cost of collecting, distributing, and sorting sidings, of which there are 38 miles at Edgehill (Liverpool), and proportionate lengths at other places. The

London & Northwestern is in no way exceptional in this respect among the great English railways.

The total actual average cost of loading and unloading freight per gross ton, exclusive of interest, was given as under for the year 1880, at the following places :

London	70.1 cents.
Manchester	41.0 "
Birmingham	34.0 "
Liverpool	39.4 "

This total cost includes everything incidental to carrying on the business of the station, but no charge for risk, breakage and pilferage, or for cartage.

PART V.

THE CONDUCT OF LOCATION.

"O, what a precious book the one would be
That taught observers what they're *not* to see!"
—O. W. HOLMES: *A Rhymed Lesson.*

"Some things can be done as well as others."—SAM PATCH.

PART V.

THE CONDUCT OF LOCATION.

CHAPTER XXVII.

THE ART OF RECONNAISSANCE.

1125. AN ART, as distinguished from a science, is something which, although it in part can be taught, yet cannot be written down in definite fixed rules which have only to be followed with exactness. A SCIENCE, correctly so called, however difficult or intricate it may be, is always in its nature susceptible of rigorous and exact analysis. An ART is not. Thus we may speak with strict propriety of the science of bridge-building, but only of the art of reconnoitring.

Nevertheless, just as there is no scientific branch of the practical work of life so purely a science that it is possible to dispense with a certain aptitude and tact which is outside of and beyond written rules, so, on the other hand, even in what is so purely an art as discerning the physical possibilities of a given region by the aid of the eye alone, certain general rules and cautions will greatly diminish the danger—which often rises to certainty—that without such aid an inexperienced engineer will fail to discern the possibilities which lie right before him, and reach wholly mistaken conclusions as to what he can and cannot do with the region before his eyes.

1126. For there is nothing against which a locating engineer will find it necessary to be more constantly on his guard than the drawing of hasty and unfounded conclusions, especially of an unfavorable character, from apparent evidence wrongly interpreted. If his conclusions on reconnaissance are unduly favorable, there is no great harm done—nothing more at the worst will ensue than an unnecessary amount of surveying; but a hasty conclusion that some line is not feasible, or that further improve-

ments in it cannot be made, or even sometimes—often very absurdly—that no other line of any kind exists than that one which has chanced to be discovered—these are errors which may have disastrous consequences.

On this account, if for no other, the locating engineer should cultivate and habitually preserve what may be called an optimistic habit of mind. He should not allow himself to enter upon his work with the feeling that any country is seriously difficult, but rather that the problem before him is simply to find the line, which undoubtedly exists, and that he can only fail to do so from some blindness or oversight of his own, which it will be his business to guard against.

1127. The chances are greatly in favor of his ultimately finding this assumption to be correct. Occasionally he may be deceived, but the young and inexperienced engineer cannot proceed on a safer hypothesis than this: That however forbidding the region, a line exists which is conspicuously better than any other, and which will in all cases be found to be—in comparison with what was expected—a line cheap to build and economical to operate; and that, on the other hand, the line which he, as an inexperienced man and acting without special training for the work, will be likely to first select as the best, is perhaps twice as costly in first cost and considerably less favorable in gradients and operating value than that which he can secure by greater care, attention, and study. Although this may seem a sweeping generalization, it is so near a general average of probabilities in both easy and difficult country, that in a rude way it may be assumed as truth.

1128. For the reason that there is so much danger of radical error *in the selection of the lines to be surveyed* (or, rather, of the lines not to be examined), it results that THE WORST ERRORS OF LOCATION GENERALLY ORIGINATE IN THE RECONNAISSANCE. This truth once grasped, the greatest of all dangers, over-confidence in one's own infallibility, is removed.

1129. The most fundamentally important technical qualification for entering upon the reconnaissance is an understanding of the economic questions considered in the first parts of this volume, especially as to what a railway should be from a business point of view, and what the relative importance is of engineering (or geometric) and commercial excellence; for if the engineer cannot correctly distinguish between the financially important and unimportant, as well as between the practically feasible and the practically impossible, he will be almost as liable to go astray as if he were physically blind, by omitting to examine as worthless the very possibilities which he should look into most carefully. It fol-

lows also that he should be well posted as to the relative cost and difficulties of construction.

1130. These qualifications being presupposed, before beginning the reconnaissance, as well as during it and after it, the nature, extent, and probable sources of the traffic, and especially of way traffic, should be carefully looked into, as a consideration which will be often—it might almost be said usually—so important as to fix the general route in despite of quite important engineering disadvantages. The small effect on profit and loss of even considerable differences of distance, and the small effect on distance of even considerable and "ugly" swerves from a straight line, may well be especially studied up, not to make one reckless of sacrificing distance, but to enable one to sacrifice it and save it intelligently.

1131. On the other hand, the engineer should with especial care disabuse his mind of the very natural feeling that what may be called his own particular and especial department—getting a cheap line to subgrade—is of much relative importance to the future of the company. He should remember that it requires a continuous cut or fill of about 7 feet, or say an average maximum cut or fill of 10 to 12 feet, with its ordinary accompaniments of masonry, to equal the cost of superstructure ready for operation; that the total investment for rolling-stock, machinery, buildings, and miscellaneous purposes will, on a line of active traffic, very nearly equal that for road-bed and track complete, and that, finally, and more important than all, the interest on the total *de-facto* investment for all purposes rarely absorbs more than from one sixth to one fourth of the gross revenue. Broadly speaking, therefore, we may say in general terms that—

To increase gross revenue $\frac{1}{5}$ we may double the whole investment.
" " $\frac{1}{10}$ " cost of road-bed and track.
" " $\frac{1}{20}$ " " grading and masonry.

These percentages, of course, are subject to important fluctuations, but the fact still remains in all cases that, for obvious reasons, the tendency of an engineer is to concentrate his attention unduly on the work below sub grade.

1132. As a more direct qualification, the engineer should prepare himself as carefully as possible to form reasonably accurate estimates of the probable cost of the work per mile on various lines and grades. The faculty of making tolerably close approximations of this kind, assisted by the eye alone, is not so very difficult to acquire, but can only be gained

by careful observation. The best manner of obtaining it is by noting the general appearance of as many lines as possible, either before or after their completion, and then comparing a guess based on this appearance with the actual cost or quantities. Experienced contractors can guess in this way within a very small percentage of how many yards per mile a given piece of work will run. The engineer should by previous practice and study have at least so far perfected himself in this art as to have some idea as to his "personal equation" or probable range of error.

1133. The danger with most young and inexperienced engineers in making estimates of the cost of work is decidedly that they will make too small estimates, influenced by a natural hope and anxiety to show good results. But, on the other hand, there are some who, especially in preliminary estimates, go to the other extreme. Just as it is the mark of an untrained engineer to make estimates too low, so it is the mark of a half-trained man to persistently make estimates too high, especially on work involving difficult or doubtful points, which it may be in question whether to attempt at all; a practice which some of them adhere to through life, from an idea that they are being thereby more prudent and "practical." Each error is equally discreditable. An estimate should lean in the direction of excess, but a moderate error in either direction is a pardonable fault (par. 21).

1134. To these qualifications is to be added—not by any means as least important, but as last in order of importance, if the intended distinction can be grasped—what is generally known as an "eye for country," the nature and importance of which has already been considered in par. 18. Such rules and cautions for acquiring an "eye for country" as can be committed to paper (which are not a few) will be given in the following chapter. The fundamental rule is to have an abiding conviction that a much better line than at first sight appears can be found by opening one's eyes.

1135. Undertaking a reconnaissance with a reasonable measure of these qualifications, it will require, often, nothing more than careful observation and one or two trips over the line to definitely determine, once for all, which is the proper general route to adopt, and so save all necessity for running any duplicate lines whatever except for short alternate sections of 2, 10, 20, or 30 miles, which are almost always necessary at points, and which may be called matters of detail. It would be dangerous, perhaps, to state that it is a general rule that only one line will need actual survey, but the writer's experience is that this is far more often true than not, and that it is true, perhaps, of a larger proportion of heavy

lines than of light lines. When all the traffic and business considerations, as well as engineering differences, have been duly considered, the writer has never known an instance where there seemed the slightest need to survey more than two general routes, although such instances may well occur. In any case the reconnaissance should be conducted always with as much care as if it was expected to make by its means a final selection of route.

In conducting the reconnaissance, while individual habits of mind no doubt differ greatly, and with them the direction in which error is most to be feared, the following rules and cautions are believed to be of universal application, the first one especially being fundamental:

1136. 1. THE RECONNAISSANCE MUST NOT BE OF A LINE, BUT OF AN AREA, including at all times in the mind as wide a belt on each side of an air line between the two fixed termini as there is the remotest possibility of the lines reaching to; "remotest possibility" being considered for the time being as only bounded by some marked and decisive topographical feature or traffic centre.

Thus, in reconnoitring a proposed line, *AB*, Fig. 266, supposed to be about 100 miles long, we may reasonably take the valley line *V* to the right, or the town *C* to the left, as the lateral limits, but nothing less than this, and the whole area between them should be studied as an area, and a topographical map "in the mind's eye" made of it all; exact comparative knowledge of all the various passes and other governing points being obtained on reconnaissance, or by subsequent survey or spur-lines.

This simple rule is one rarely thought of or acted on until repeated blunders have enforced it. Error is particularly liable to follow from neglecting it, as will be shown later by a few examples from practice. We may *survey* lines, but we must never reconnoitre them. If we do, it is not a reconnaissance.

1137. 2. All prepossessions in favor of any particular line must be abandoned, especially in favor of that line which seems most obvious. The importance of this is too obvious to need dwelling on, yet it is one thing to admit it in theory and quite another to do it in practice. Not to do so is a dangerous and frequent error.

1138. 3. A tendency to see with undue clearness the merits of LINES LYING CLOSE TO HIGHWAYS or the more settled and open districts must be carefully guarded against. This is another dangerous and frequent error, which is always imminent, partly because it seems too obvious a danger to be a real one. The writer now recalls no less than thirty instances, some of them of the first importance, in which the deceptive conveniences of highways alone were responsible for serious error, as

in the instances of Chapter XXIX. and Appendix C. Allied to the above are:

4. Lines hard to get over on foot, or overgrown with timber or tangled undergrowth, seem infinitely worse by comparison than they really are; and,

5. Raggedness of detail, sharp rocky points, steep bluffs, and the like, exert an entirely undue influence upon the mind as compared with long rolling slopes spread out over a longer distance.

These two dangers are so imminent where the conditions specified exist at all, as in comparing many valley lines with ridge lines, that they will be separately discussed (par. 1162). The disadvantages of a route for a railway must not be measured by its disadvantages as a foot-path, even after all brush and timber have been removed, yet it is hard not to do so to some extent.

1139. 6. A complete mental map of the watercourses should be made as the reconnaissance proceeds—sufficiently exact, at least, to enable the engineer to state positively where the water of every stream crossed joins another, and what streams run in together, until they have passed off the limits of the AREA under examination.

It is not always convenient to do this for each stream as it is passed, without undue delay; but wherever a stream is passed without doing it, *there, it should be noted, is a gap in the necessary knowledge of the country*, which may be dangerous.

A skeleton framework for this information can generally be obtained from maps. It is in respect to the minor streams that the caution is particularly necessary, and it is even more important to adhere to it in the smoother than in very rough country. Neglect of it often carries one off on a false track.

1140. 7. FALSE SUMMITS, or those which appear to interpose between two water-sheds, when in reality they are only between different parts of the same water-shed, are very liable to deceive under certain circumstances. The latter, fortunately, do not often occur; but when they do occur the deception is often very perfect, introducing an apparently impassable obstacle to the progress of the line which is only apparent. One of many reasons for the preceding rule is to avoid this danger.

See also OVERLAPS (par. 1161), which are a kind of imaginary false summits.

1141. 8. As a very necessary safeguard against error, the engineer should MAKE IT A RULE to invariably discredit all unfavorable reports, from whatever source derived, which do not accord with what he expects.

This merely means that if he has, or thinks he has, any reasonable shadow of ground for hope that certain things are possible at controlling points, he should go there and look for himself before he finally abandons hope. Not un-

frequently he will see reasons to be glad he did go. The time of a man who may have been previously sent to the point is not therefore lost. Assurance is at least made doubly sure, and he might have brought back a favorable report; but the most trusted assistants are liable, with the best of intentions, to reach entirely wrong conclusions by looking in the wrong place or seeing the wrong things.

1142. The reconnaissance, it should be understood, although spoken of as one continuous and complete examination of the territory, is not necessarily completed all at once. On the contrary, it should in a sense be always in progress until the final location is complete, and may well be made in part while a party is running some first experimental line. It may also continue over a number of separate and complete trips over the route, which in a literal sense are examinations of so many distinct lines; but it should never be felt to be so while making the trips, but as broad a belt should be taken in, in imagination at least, as it is possible to keep in mind. The feeling should always be present in the mind of the engineer that he ought to be somewhere over the edge of the horizon, or on the other side of the valley or ridge, instead of following his nose where he is.

1143. The whole reconnaissance is not ordinarily carried on in the field, but a part of it, small as respects time, but often important and even decisive as respects results, is obtained from the study of such maps of the region as may exist. The same arguments apply to such examination as to examinations in the fields, and the same methods should be used. The obvious should be mistrusted and the improbable looked for hopefully. An examination of maps may in some cases be the only reconnaissance, properly so called, needed, as when a line follows for its entire length a deep valley of known character between points both situated in the same valley. On the other hand, the reconnaissance may show such nicely-balanced possibilities that three or four exploration lines will be necessary, merely to form a clear idea of what lines to examine in earnest.

But, as a general rule, neither of these conditions prevail. A careful reconnaissance is necessary, but it is also decisive; showing beyond doubt (at least any doubt which a survey by the same persons could remove) that some one route is alone worth careful survey, or at most two.

1144. The method of making a reconnaissance may be in detail somewhat like that sketched in Fig. 266. Such ordinary matters as that water runs down hill; that streams start at their source from the lowest point in their immediate vicinity and flow toward still lower ground; that large streams usually lie lower than contiguous smaller streams, and

that an aneroid barometer will be of assistance to fix the approximate elevation of points, if too great confidence be not placed in it,—may be supposed to be understood.

A hand-level is a more important tool, which should always be at hand. In looking through it do not close one eye, but while one eye looks through the tube of the hand-level let the other look at the natural landscape The bubble will then be seen superimposed on the latter. Hand-levels are very often out of adjustment, and still more often have very dull bubbles, which read quite differently if the tube has been raised or lowered to position. A guess should always be made first, before using the hand-level, but no man ever acquires a very trustworthy faculty of guessing at a horizontal line. In ordinary localities a practical eye will estimate elevations and a horizontal line with a good deal of precision, but there are peculiar topographical conditions which make the evidence of the eye worse than worthless (par. 1160), and no one can tell where they are in advance.

FIG. 266.

An odometer may be fastened to the wheel of the carriage, if a vehicle be used; but distances can usually be guessed or ascertained, by time estimates or otherwise, nearly enough for preliminary purposes. A pocket compass is a necessity, and a succession of travelling companions with a local knowledge of the country are very desirable. More outfit than this and the best attainable maps will not be particularly useful.

1145. As a preliminary to starting out to explore, say from B to A, Fig. 266, one should strike an arc mentally across the country with B as a centre, and with a radius of 2 to 20 miles, according as some definite topographical feature may indicate. In country at all rough this arc should be at least 200° long. In smoother country it may be less. A pass through a range of hills at e on the direct line to A may determine where to strike this arc.

Before allowing himself to pass by this arc *at any point* the engineer should mentally ask himself this question, and either answer it positively and definitely on the spot, or note that he must find an answer: How many different routes are there, and what are their comparative merits, for passing from B TO BEYOND THIS ARC at any point in its whole extent? If there be some point like e or f which is, in the first place, out of the proper direction; secondly, difficult of access; and, thirdly, highly unpromising in appearance,—it must not be passed until it is known that it is not feasible, or else noted as a point to be continually remembered as of unknown and presumably great capabilities.

Usually there will be three or four routes for crossing this first arc, which will appear distinctly better than any others, and perhaps be the only possible ones. Noting every one of those which have not been examined, and assuming that everything is possible which is not clearly seen to be impossible, the imaginary arc may be crossed to the next belt.

1146. Here, at some fixed topographical feature where obstacles occur, or at some town, a second mental arc may be struck, likewise with B as a centre, but it is no longer necessary to make it 200° long, but merely long enough to cover a route to A from every possible pass of the first arc, and the method should be the same. The question should be: IN THIS ANNULAR BELT what is the best way to pass from *some* attainable point in the first arc to beyond the second, and which will give the best complete route from B?

By this time we shall be so far away from B that we cannot really cover mentally, even in the rudest way, all the area we should investigate, and we must drop the furthest half of it entirely from mind for the time being. Remembering that it is dropped, however, the method is the same, so far as it goes. By assumption, all the most hopeful chances are in the region beyond the horizon, but it is necessary to leave them for the time being.

1147. As the reconnaissance approaches A it will be more natural that our work should be carried on with that as a centre, and as soon as possible the examination of the whole possible area at once, in a cursory

way at least, should be resumed. On reaching *A*, before the territory passed over is again examined, all the remaining possible area should be gone over in the same way, and it should not be regarded as completed until the limits of the water-shed of every stream in the whole area are well understood, and the lowest passes through the ridges. It is not by any means the roughest regions which require the most care in this respect. Thus, in Fig. 266, if the country were very rough the chances would be very strong indeed that the valley-line *BVA* would be the best, and a very cursory examination of some cross-line *VD* might suffice to prove it. In moderately easy country the line *BCDA* would be far more likely to be the best, and there might of course be considerable variations in it; or the valley at *bc* might be so low and the town *C* so small that the preference clearly lay with the most direct line. It does not by any means follow that the whole area should be examined with equal care. If one part is positively known to be worse than another, it matters little to determine how much worse; only, it must be known, and not guessed at.

By following strictly on the line of these suggestions serious oversights are not probable; otherwise they are exceedingly probable. Such assistance as it seems possible to give for training the eye to take in the meaning of what it sees before it, is given in the following chapter. One general caution may be added: "ROUGH COUNTRY" is a purely relative term. To the tyro, the rolling hillocks of Ohio, Michigan and New Jersey are rough. The same man, with a little experience in really rough country, will take the worst the Rocky Mountains or the Andes can offer with equanimity; and equanimity is in every calling essential for success. No country in which most of the surface has a layer of soil over it deserves the name of rough. It needs but little study and care to get several lines of reasonable cost through it. The art of location consists merely in making a judicious choice,—not in getting *a* line, which is always easy in such regions.

1148. An accomplishment which is not very difficult to acquire, and which is constantly useful on reconnaissance, is to estimate the rate of fall of streams from their general appearance. No general rules can be laid down, because so much depends upon the volume of the stream. A fall of 4 to 8 feet per mile will give a good-sized stream or river a very rapid current, with many stretches where it will seem to the careless eye as if there were nearly that fall at a single point, succeeded by pools above and below. On the other hand, a fall of 30 or 35 feet per mile does not necessarily give to a small-sized river the character of a torrent, and large brooks or small creeks must fall 100 feet per mile or more before they have any violent current.

1149. A special report on the Water-Power of the United States in the Tenth United States Census gives a tabular statement of the slopes of the principal streams flowing into the Atlantic and the Eastern Gulf, which might perhaps be profitably abstracted. It shows that the slope of the streams is pretty much the same per mile from the Merrimack to the Chattahoochee; the average slope of twenty one main streams being 5.4 feet per mile, with the Susquehanna the flattest, at 2.8 per mile, and the Hudson River the steepest, at 10 feet per mile.

The slope of some of the southern tributaries of the Ohio River is very light, ranging from 0.41 foot per mile for the Green River to 2.84 feet for the Allegheny as a maximum. The falls in these streams generally take the form of long shoals. As an example, however, of how very quickly some of these rivers descend from their elevated sources to the gentle slope of their subsequent course, Mr. Dwight Porter mentions that the Cheat River, in West Virginia, falls 2400 feet in the last eighty miles of its way to the Monongahela, while the latter river descends but 75 feet in the ninety miles between the mouth of the Cheat and Pittsburg. The northern tributaries of the Ohio have usually steeper slopes, but the average is far below the rivers on the upper Atlantic coast. The Ohio River itself, from Pittsburg to its mouth, a distance of 967 miles, falls 430 feet, or an average of 0.44 foot per mile. At Louisville there is a fall of 26 feet in two miles.

The Upper Mississippi, from its extreme sources to St. Paul, 500 miles by the river, falls 1000 feet. The Missouri River falls 2464 feet in the 2644 miles of its course below Fort Benton, being navigable to that point. The tributaries of the Mississippi from Eastern Iowa have a general slope of about 3 feet per mile, ranging from 1.84 to 3.83 feet per mile.

The Arkansas River, from its source to Pueblo, Colorado, averages 34.11 feet per mile. In the upper 120 miles the river falls 40 feet per mile, then flattens out to 8 feet per mile for 500 or 600 miles, and at 150 miles above its mouth its slope is only 0.46 foot per mile.

The Niagara River, in its short course of 37 miles, descends 333 feet to Lake Ontario with a vertical plunge of 160 feet at the Falls, discharging a volume of water nearly half as great as the Mississippi River, or 166,600 cubic feet per second. From Buffalo to 3 miles above the Falls, the river descends 20 feet, or about a foot per mile, yet the stream is readily navigable; from this point to the brink of the Falls it descends about 53 feet, or 18 feet per mile.

CHAPTER XXVIII.

OCULAR ILLUSIONS.

1150. THE natural eyesight is readily deceived even where the apparent differences are so great as to seem clear and positive. Among the more serious ways in which this danger may make trouble are:

1. *The eye foreshortens the distance in an air-line and materially exaggerates the comparative length of a lateral offset,* so as to greatly exaggerate the loss of distance (and hence of curvature) from any deflection. A deflection which will not in reality add more than 10 to 15 per cent to the length of a line will seem to the eye to double it. This marked tendency to great exaggeration results from the effect of two concurrent causes: (1) the foreshortening alluded to, and (2) the tendency of the mind to exaggerate the distance lost by lateral deflections even when looking down upon a map—as Fig. 13, page 237, where the loss of distance in *C* might be easily estimated at four or five times what it is.

These two causes combined, both of them having much effect in the same direction, make the judgment of inexperienced men on this subject almost absurdly deceptive.

1151. 2. *The eye exaggerates the sharpness of projecting points and spurs, and the degree of curvature necessary to pass around them:* an exceedingly common difficulty, leading to serious consequences. It results from a combination of natural causes, viz.: (1) The eye, in looking at all natural slopes, from any point of view whatever, greatly exaggerates their steepness. A 60° slope seems almost vertical; a 45°, fully 75°; a 1¼ to 1 slope (the rate of the very steepest mountain sides), at least 1 to 1; etc., etc. This tendency is especially strong in looking at slopes from above. (2) Such points are generally looked at from above; but whether looked at from above or below, the eye instinctively searches for something fixed and definite to start from, *which is usually found in the crest or ridge line,* especially if the latter runs nearly to a knife-edge. Likewise the eye almost invariably tends to exaggerate angles, from whatever point the view is taken on which the judgment is formed. If formed from the side (Fig. 267), it exaggerates the distance *C* in comparison with *AB*; making

it seem half as long, for example, when it is only one fourth as long, thus making the point seem to require a curve of 180° where perhaps 110° only will suffice. If formed from in front of very sharp points, Fig. 268, the tendency is to look upon the two range-sights, *B*, *C*, as at a much sharper angle *U* to each other than they really are, *because the eye ranges along both slopes at once*—an unusual circumstance, the more common case being that of Fig. 269, in which the tendency is in the opposite direction. In Fig. 268 one tends to approximate

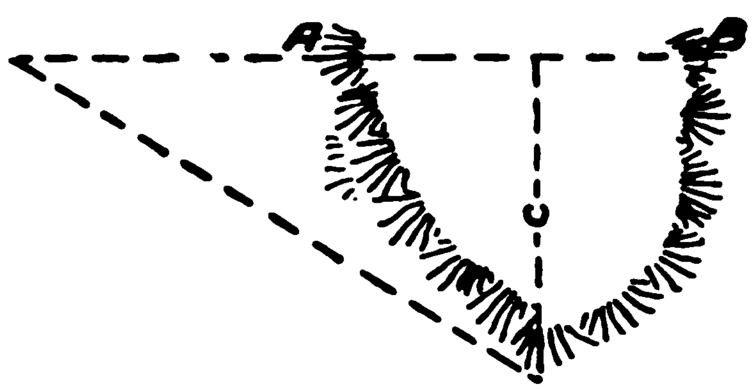

FIG. 267.

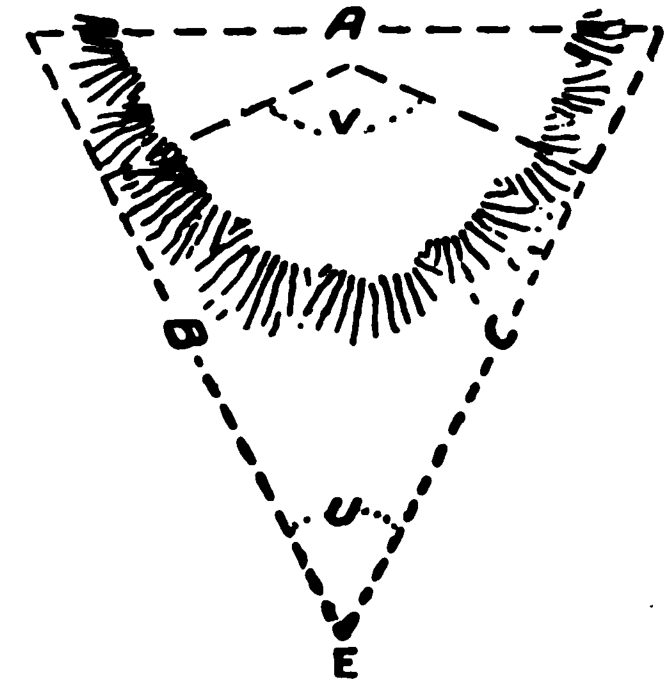

FIG. 268.

the angle *V* to 180°; or, in other words, to think of *B* and *C* as nearly parallel to each other, as if we were looking from *E* at an infinite distance.

1153. From these causes combined, the eye at *E* first fixes on the crest-line and then exaggerates, say, a 1½ to 1 slope into a 1 to 1 slope; in other words, makes the chord-line *A*, Fig. 268, one third shorter than it is. This alone gives a 15° curve where 10° will suffice. But having first got our chord-line too short, we then proceed to mentally exaggerate *the angle to which it is a chord*, and thus still further shorten the supposed radius, so that we may easily picture a 20° curve where 10° would prove on survey all-sufficient.

Whether this explanation of the philosophy of the tendency to error be correct or not, the fact of its existence in about the degree stated is beyond question, especially with those who are for the first time confronted with "rough country." They are almost sure to exaggerate greatly the difficulties of such localities.

1154. 3. An opposite tendency—to decrease the probable angles required—exists in looking at smooth gentle slopes, especially from a distant point of view, for reasons hinted at in part in Fig. 269. Smoothness and gentleness of slope mean that we must either go out a long way to gain a little difference of elevation, or must put up with very long, if not very deep, cuts or fills. In order to bring down the work to reason-

able lightness, therefore, we must often adopt a quite crooked alignment on the smooth and (for foot travel) very tractable slopes, and even then have pretty heavy work.

This error is especially liable to occur on the long gentle rolling slopes which are met over vast areas of the far-western United States, Mexico, South America, and (the writer believes) much of Asia, Africa, and Australia, in all of which regions Nature seems to have planned all her works on a vast scale and taken plenty of room to spread out in. In the Eastern United States and in Europe west of Russia it is less imminent.

Fig. [illegible]

When we happen to be comparing two lines, one of which lies, say, in a valley, where the tendency is to exaggerate the sharpness of curves and angles, while another lies on a smoother and higher region, where the tendency is in the other direction, these two opposite tendencies may combine to cause most calamitously mistaken conclusions, one line being made up in large part of points like Fig. [illegible] and the other like Fig. [illegible].

1155. The unassisted eye is also liable to be deceived in many ways as to gradients and elevations, as notably in the following:

a. A slope seen [illegible] from a distance always appears steeper and higher than it really is, especially if we are standing on ground descending towards it [illegible] the slope where we stand [illegible] to exaggerate [illegible] to an absurd extent the steepness of the rising ground in front. This is a familiar experience [illegible] more or less. The best [illegible] the phenomenon [illegible] the effect of a given vertical angle [illegible] surface, for the [illegible], as on a railway [illegible] where, on the [illegible] as it were, "discounted" [illegible] less impression.

1156. [illegible] this and many other [illegible] and training of the [illegible] absolutely no per[illegible] but puts out his

hand to touch everything he sees within his field of view, even on the distant horizon. To measure distances and sizes as accurately as we do by the aid (1) of the short base-line of 2½ inches between the two eyes, and (2) of our gradually acquired knowledge of the probable sizes of objects, is really a mental process of extraordinary difficulty and delicacy, which is only acquired by the incessant, unconscious practice of years. Under the conditions in which we have been most trained we do tolerably well; but whenever we strike the unfamiliar and unusual, then the eye reverts to its original untrained tendency to bring everything in the distance up into its own vicinity, with an inevitable distorting effect on what the mind makes out of the picture seen. Thus it is that the sun and moon appear to the eye a great deal larger when they are rising or setting, the mind never admitting that they can be very far off, except when forced to do so by seeing them beyond the immediate horizon. Thus, rather than by the common explanation that there are no intermediate objects to fix on, distances across water are always under-estimated by those unaccustomed to it. For the same reason, possibly, the eye brings forward the farther end of a long line of rails beyond a hollow until—aided somewhat by the further assumption that we are standing on a level—they seem almost to stand up and down. For the same reason, the steepness of the slopes of mountains are exaggerated; and possibly for the same reason, in part at least, the immense scale on which the topographical features of the great West, Mexico, South America, and

FIG. 270

similar regions are laid out, deceives as to distances the Eastern man or European, accustomed to a pettier topography.

1157. A comparison of the different effect upon the eye of railway gradients and natural slopes of the same rate, wherever two descending

gradients can be found nearly following the natural surface, is an instructive training of the eye. By standing first on the track and then a few hundred feet to one side, the difference in the degree of the deception is marked; but trial from various points of view will show that it always exists, even on the natural surface.

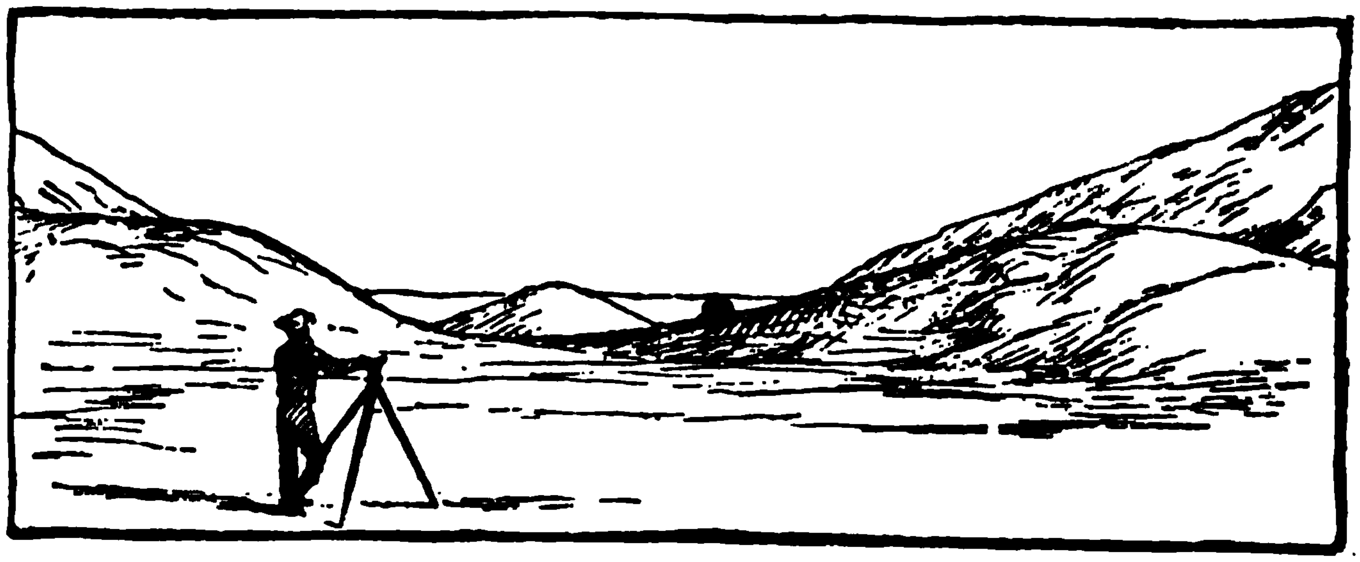

FIG. 271.

1158. 5. Allied to the above, but operating more obscurely and on a larger scale, is the deception which comes from THE PROPINQUITY OF LARGE MASSES OF HILLS OR MOUNTAINS when looked at from a distance, or even from a mere general slope in one direction of the whole foreground within view, especially if it be much broken up in detail by minor hillocks and ridges, so that the general trend of the surface is not readily detected. The best-trained eye is quite incapable, under these circumstances, of estimating horizontality so as to detect the lowest points with the same success as under ordinary circumstances. Fig. 212, page

FIG. 272.—A DISTANT VIEW OF AN OVERLAP.

680, reproduces admirably an ocular illusion of this kind. The grades against the stream seem enormously steep, and those with it nearly level. The reverse is the case at the viaduct in the background, yet everywhere the rate is the same. In Fig. 270 the pass *A*, which seems to the eye of a distant observer to be slightly lower than *B*, may be counted on with great certainty to be considerably higher. To be in fact on a level with it, it must appear to the eye very much lower. Fig. 270 was sketched

from an instance where half a dozen skilled men under-estimated the height of *A*, and over-estimated *B*, by nearly 200 feet, from a point of view less than 3 miles off, over an apparently level plain, on a line of sight nearly parallel with the slopes of the mountain, and with *A* and *B* hardly more than half a mile apart; the pass having been looked at, likewise, from both sides.

1159. Another, the most extraordinary ocular deception which the writer has ever encountered, and for which he could not then or later imagine an explanation, is badly sketched from memory in Fig. 271. In a gently rolling but much "accidented" country, through a little pass with (seemingly) long gentle slopes on each side, the little hut appeared only 10 feet above the bottom of the notch less than 400 ft. off, when in fact it was 80 ft., there being in this case no preponderance of large masses on either side of the field of view to unbalance the eyesight. This deception, likewise, was common to every man of a large and experienced corps, and perhaps came from an obscure train of association with a sharp and tremendous descent a short distance back (1500 feet in a six-mile view), which might have been seen in part by eyes in the back of one's head while looking at the hut, but which neither existed in fact nor appeared to exist in the view taken in by the natural eyesight, as rudely and very inadequately sketched in Fig. 271. The hut looks far too high in the cut, and the very bottom of the valley was in sight.

1160. Similar ocular illusions, and perhaps more remarkable ones, may be seen wherever there are irrigating or other nearly level ditches winding around the slopes of mountains above rapidly descending val-

FIG. 274.—THE SAME OVERLAP—NEAR VIEW.

leys They invariably appear to run up hill, and often in a very marked and extraordinary way, as with many of the irrigating ditches of Colorado.

These examples are but pronounced types of frequent topographical irregularities, which make the eyesight utterly worthless for measuring important elevations and slopes in certain localities; and where those localities are, unfortunately, cannot be determined in advance. The aneroid barometer, altazimuth, or hand-level, consequently, should be

constantly used on reconnaissance, and, in general, all such points, if important, should be actually visited, for another reason:

1161. 6. OVERLAPS of hills or elevated ground at a distance are a frequent source of deception and error. Views which from a distance appear like Fig. 272 are found on nearer acquaintance to be more like Fig. 273, with an easy, open valley, and perhaps a running stream passing through what seemed to be, "beyond question," a solid ridge. Illu-

FIG. 274.—BETTER COUNTRY THAN IT LOOKS.

sions of this kind are often very perfect, even in the near vicinity of the observer. An example on a small scale (small, because the mind realizes that it must be a deception) may be seen in ascending the Hudson River when approaching Peekskill, especially in the early summer evenings, when the lights and shades are such as to produce a very vivid feeling that it is a closed basin without further outlet to the north. It is said to be on record that it deceived Hendrick Hudson himself, and almost induced him to turn back.

culty of work follows from the mere act of thoroughly clearing the ground, even if there were nothing on it before but light undergrowth and brush. To a thoroughly trained eye this should make no appreciable difference, yet the unconscious feeling of every one is "well begun, half done."

1163. When to ordinary timber we add tangled vines and undergrowth, making progress on foot exceedingly slow and difficult, this effect is increased. We are apt to measure distances by time under such circumstances, so that, if we went over an aggregate of 10 miles at one mile per hour, and of 90 miles at five or six miles per hour, in exploring 100 miles, we shall finish with a feeling that fully a third of the line has been very rough. On the other hand, when we strike a highway and go along rapidly over the ground, we at least never exaggerate the difficulties which we walk over the hill to take a glance at, and the long stretches of easy country are what we have been most conscious of and remember most vividly.

In Fig. 274 we have a sketch of a jagged rocky point in a river valley; in Fig. 275 a sketch of a line on a gently rolling side-hill. Nine men in ten will be rather appalled by the rocky bluffs and take the side-hill line very calmly; yet the chances are very strong that, mile for mile, the valley-bluff line will be the cheapest, in addition to having the best grades.

1164. This results from the fact that in following a valley-line it is exceedingly difficult to make due allowance for the fact that NATURE HAS MADE OUR FILLS. It may be necessary to hit such a rocky point as that in Fig. 274 pretty hard, but never very hard, because before we have done very much work on it we have excavated enough material to carry the line past it on a fill, even in a raging torrent; and hence we are not obliged to hug into the point, as on ordinary ground, to avoid running our line above all supporting ground in the hollow beyond. There are no hollows beyond. As soon as we have passed this point we come, probably, to a narrow but sufficient stretch of bottom-land, already rip-rapped with vegetation, and already standing, as all bottoms do (when there are any) in such valleys as that pictured, just above the ordinary level of high-water, so that they are not often overflowed deeply (usually once in 10 to 30 years), or else, when they are overflowed, are not submitted to a destructive current. The more violent and rapid the ordinary current the less likelihood there is that the bottoms are often destructively overflowed. If overflowed, the current cannot be rapid, or the bottoms would wash away.

Therefore, when we have passed the rocky bluff in Fig. 274 we have

comfortable running, and can get a good alignment until we come to the next similar point. At every one of them, although we are thrown out to and into the water, Nature has provided the material to resist the water on the spot. The profile of such a line is very apt to be quite light; rather deceptively so in fact, since there will be a great deal of work in protecting banks and working very steep slopes, which will not show on the profile at all.

1165. On the other hand, in Fig. 275, gentle as is its general effect, we must cut into our hills far more than the eye will appreciate in order to avoid enormous fills. If the slopes be at all steep (they might well be steeper in the view to bring out the effect desired), the eye when reconnoitring will underrate the depth of these fills, especially from a distance, by taking a mental section of them ***on a plane normal to the slope*** instead of on a vertical plane. The loss from the side-hill slope of the ground, likewise, will be very likely to be under-estimated: not that the eye will not exaggerate the slope of the ground relatively to the horizontal, for it will, but, by a seeming paradox, the angle of the ground with the side-slopes of a cut or fill will be rather underrated, because the mind mentally exaggerates the latter also, and still more.

It is almost an invariable rule that fills turn out deeper than they are expected, and on a side-hill line most of the water-ways are in fills of considerable depth. The water channels are also more ramified, and hence more numerous, on high slopes than lower down in the valleys, where the total discharge is more, but the water has collected in larger streams.

Much expense can be saved on side-hill lines, and danger of washouts as well, by catching the water in a ditch at or a little below grade and carrying it under the road-bed in a small structure, with the foundations of the discharging end of the structure properly secured, instead of putting the structure in the very bottom of the gulch.

1166. CUL-DE-SACS are another incessant source of deception and error, although rather due to negligence or inexperience than to ocular illusion proper. It constantly happens that men walk into them as a mouse into a mouse-trap, and for the same reason—blindly following one's nose; or rather, from reconnoitring a LINE, foot by foot and mile by mile, instead of an AREA as a whole. A man sees a beautiful open area ahead of him as far as the eye can reach, probably with a highway through it. He is satisfied, and looks no farther, until he comes to the end of it. THEN IT IS TOO LATE. He has accepted his line so far as a finality, and knows no other. He assumes that he can do nothing better behind, and "therefore" must get out of his trap ahead as best he can. Unless he is confronted with very great difficulties, he is likely to do so. To read in

cold print, this seems an improbable bit of stupidity. It is one of the commonest of faults.

1167. A single instance on an important survey, affecting 40 miles of line, will illustrate how it happens. In a very broad flat valley which extended for six or eight miles farther a dry run was encountered. It was assumed to drain to the west, and passed as of no moment. It really drained to the east, through a small rocky overlap about two miles off, which opened out half a mile beyond into a broad open valley leading directly to the desired terminus. The *cul-de-sac* gave a fine line as long as it lasted, and then over 20 miles of rather heavy work, with bad grades and bad curves, yet it was run by an engineer of large experience, and came very near being built.

1168. Of all these types of ocular deceptions there are many variations. To thoroughly guard against them comes with experience alone, and rarely with that. Until they have been learned by experience, and the engineer's "personal equation' determined, very wide limits of error alone can be safely assumed. Nevertheless, provided the danger of error be realized, it is not a particularly serious one, because errors of the eye will be checked by surveys. The greater danger is that the untrained eye will tell such wholly delusive tales as to make the worse appear the better course, and cause that line or part of a line to be rejected without survey which was really the best. To guard against this danger, and not to advise substituting the eye for the precision of surveys except within known limits of safety, this chapter has been written.

1169. A single example of the way in which ocular illusions and some of the causes mentioned in the previous chapter may combine to lead to wrong conclusions by errors of reconnaissance, pure and simple, may be of value to save the student from underrating the magnitude and imminence of the dangers against which he has been cautioned. It summarizes the facts of a very important piece of line on which a number of causes combined to bring about calamitously wrong conclusions. Those particular causes for wrong conclusions against which cautions have been given are printed in italics. The map is modified somewhat, but the other conditions are in no way exaggerated. Appendix C contains another example, and the writer had made a list of nearly a dozen others which he had intended to annotate similarly, but space forbids.

The line was about 100 miles long from *A* to *G*, Figs. 276–7, through a region of much difficulty after reaching the crucial point *B* or *B'*, where an exit was to be found from an easy open basin surrounding

A. An established and much-travelled highway followed the general route selected, *ABCFG*. *The pass B was a little easier than B'*, and seemed for special reasons much easier than it was. *The difficulties of construction were distributed* over almost the entire line *ACG*, so that,

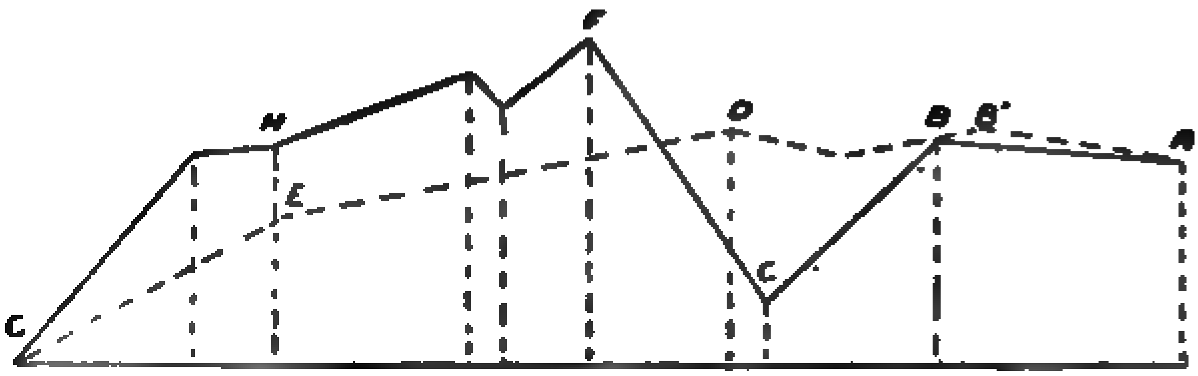

FIG. 277.

although a costly line in the aggregate, the work was at no point of a specially forbidding character.

Another route, *AB'DEG*, for these and other more pardonable reasons, was not even examined until too late. The pass *B'* was slightly

higher and more difficult of approach. Upon reaching it the outlook for the next few miles, to the pass D,—which was indeed visible from B, *but could not be recognized as a pass from that distance owing to an overlap*, so that the mountain range appeared unbroken,—was over a deep and ugly basin, and so was exceedingly forbidding, admitting of easy grades but plainly requiring heavier work and worse alignment to get them than any stretch of equal length on the other line. On the other hand, *the entire difficulties of construction were concentrated on this short stretch* of 6 to 8 miles. Once through the pass D (*which could be reached from B' only with much difficulty and a long detour*), an open and unobstructed valley admitted of a light and straight surface-line for some 60 miles to the point E,—a traffic of special value to the line being distributed from E to H. At E a valley was struck leading by a comparatively easy descent directly to the terminus G, whereas the other line at H' was so high above the valley that a costly side-hill descent on a heavier grade was the only resource. The comparative profiles of the two lines are shown, without exaggerating the contrast, in Fig. 277.

The dotted line was in this case superior in every detail, unless possibly in cost, for the stretch $B'D$, although not over 8 miles long, was more costly than any 40 miles on the other line. But the grades were materially better, the line shorter and with less curvature, and the local traffic it offered was many times more valuable than all on the other line put together.

1170. The error on reconnaissance *lay in passing the point B* without completely investigating all the possibilities of the line $B'D$ before leaving it, and so determining for a certainty that the possible line turning off through the gap to the left not only began bad, but continued bad. ONCE HAVING PASSED THROUGH B, and accepted that pass as a finality, the case was hopeless. The two lines then speedily diverged from each other completely, till they were 40 miles apart and 1500 feet different in elevation. C then became another fixed point, from which there was no possible escape. F and H' in their turn followed; and when at last the long and open valley E came within sight, the false premise that *B must be the pass*, now 70 miles behind, made it a legitimate and logical conclusion that it offered no possibilities for consideration.

1171. Had the reconnaissance happened to begin from G, the error would, in this particular instance, have been avoided, for the natural line $GEHD$ would almost certainly have been followed in the first instance, no natural line whatever existing in the direction $GH'F$, so that a

large portion of the whole cost of the line was concentrated on the initial stretch *GH'*.

This very circumstance, however, with the conditions of relative advantage reversed (especially with the pass *B* a little less tempting and no highway along *GFCA*), would have been almost certain to result in an error precisely similar in principle, with a reverse result. Starting at *G*, the fine open line *GEH* would have been followed with increasing certainty that it was the only line to take, the possibility *GH'* having been turned from as out of the question or perhaps impossible (almost certainly the latter with an inexperienced man, for it took much skill to obtain it). Arriving at *D*, the reconnoiterer would find himself in a *cul-de-sac*, caught in the mazes of his own negligence and hasty prepossessions. A beautiful line was behind him, but 8 miles of tunnels and viaducts were before him, from which there was absolutely no escape without going back again to *G*, ***mentally as well as physically***, and picking out the line *GHFC*, every foot of which, while nowhere excessively difficult, was a forced line, resulting from having got into the hole *C* and having to get out of it somehow in the direction *G*. Under these circumstances, there being but the two lines, so widely separated, it would have been well-nigh a certainty that, had the reconnaissance began at *G* instead of *A*, the tempting plains *GD* would have proved an even more irresistible bait than the pass *B* to bias the mind against fair and complete examination of even the possibilities of the other line.

1172. The writer is able to give no more apt illustration than this of the importance of following the seemingly over-minute instructions of this and the preceding chapter, whether because of the importance of the instance, or because of the salient and marked topographical features, which do not confuse the mind with a multitude of detail. There was just one point on the line of reconnaissance, and that point one affording a most forbidding and helpless outlook, where there was reasonable chance to discover the error. ***Guessing*** that an overlapped mountain eight miles off had no pass through it, and that, even if it had, the ragged eight miles which could be seen meant a ragged eighty miles beyond it which could not be seen, and which was smooth as a prairie, caused the error. Examples might easily be multiplied of similar errors, and some of them, as in the instance mentioned in Appendix C, of much greater magnitude. Valley lines are particularly apt to be rejected in this way, without thorough examination, because of supposed obstacles which are largely imaginary.

CHAPTER XXIX.

WHEN TO MAKE SURVEYS.

1173. THE reconnaissance having been thoroughly and carefully made, the most important part of the location is, in general, concluded. For, assuming all business as well as topographical questions to have been as carefully weighed as is possible in advance of surveys, a difference between any two lines which cannot be detected by such an examination can hardly be a vital one, seriously affecting the future of the property.

Nevertheless, although really ruinous errors can rarely come from an inadequate amount of surveying or from imperfect balancing of their nice results, good or bad judgment in the conduct of surveys may well make a large difference in the earning capacity of the line, and a still larger difference in first cost,—that so often vital consideration for the original projectors.

1174. Drawing an analogy from the construction of a building, the reconnaissance is like the selection of the site for a building, the determination of its size and general plan, and the rough but (in skilled hands) close guessing at the cost of comparative plans. The survey is like the preparation of the detail plans and exact estimation of cost. The construction of a railway is like the construction of a building after all these details have been determined.

1175. The seeming paradox is yet true, that both too much and too little time and money is generally devoted to surveys. Too many miles of line are surveyed, but that which is surveyed is not surveyed as well and thoroughly as it should be. The perhaps dangerous assertion (dangerous because it may give an excuse for hasty and over-confident conclusions) has already been made (par. 1128), that more often than not there is only one general route between two points to be connected by railway of sufficient comparative promise to justify even a flying line over it; but good and certain reasons should appear for failing to run at least two lines. Doubtless sometimes there may be real necessity to survey three or more lines, but the writer has never happened to meet such a case. Considerations of policy, however, often require the running of numerous

lines for which no engineering necessity exists; and in the study of the details of location, over distances of one to twenty miles, there are often a dozen or more different lines or modifications of lines, which will require to be attentively studied.

1176. The true method of determining whether or not there is need to survey more than one general route is this:

Having carefully examined, in the manner detailed at length in the preceding chapter, every possible line, and having gathered as full details as possible of the actual cost and gradients and resulting traffic and earnings of other lines from previous experience and study of recorded results, a maximum and minimum estimate should be made of each; that is to say, it should be said of each, "This line will apparently afford gradients of — per cent, which estimate cannot (guarding well the 'cannot') be in error more than — per cent either way, giving a range for possible error of judgment of from — to — per cent. Its cost will apparently be about $———, and cannot range above or below this estimate more than — per cent either way. It will reach (such and such) sources of traffic more (or less) than the other lines, which cannot add less than $——— per annum to the net revenues of the company, and might add as much as $———. In the minor details of distance, curvature, and rise and fall it has advantages (or disadvantages) which may be considered as liable to affect the future revenues per annum of the company by from $——— to $———."

If, then, after making, with more or less elaboration, an estimate of this kind for each of the various possible lines, it be found that, taking the most unfavorable view deemed possible of that line which seems the best, it is still a better line than the most favorable possible result from any of the others, it is a waste of time and money to survey more than one line.

1177. In the application of this rule there is real danger of error, but the danger lies, not in the rule itself, but in careless or over-confident application of it; not in taking mere guesses at maxima and minima as decisive, but in failing to make the limits wide enough. Even with the most elaborate precautions all human judgment is fallible. No amount of surveys will do much to prevent an incompetent man from selecting and building one of the many possible wrong lines instead of the one right line which he should have chosen. On the other hand, no amount of skill and experience will make a man's unassisted judgment as to the absolute results of a possible future survey anything more than the rudest of rude approximations. Nevertheless, the most inexperienced engineer

knows that a line in average country cannot cost more than the St. Gothard Railway nor less than the cheapest line he can find record of over the Illinois prairies, and that the grade which he can certainly attain lies somewhere, say, between a level and 2 per cent. A moderate amount of experience and skill enables these limits to be much contracted, while still leaving margin enough to afford as nearly absolute safety as is possible in human affairs. It is in the rash and over-confident fixing of the limits that the danger lies,—and it is a great one,—and not in the deliberate and conscious acting upon them after once fixing them; for it must be done consciously or unconsciously in any case, sooner or later.

1178. Acting upon the rule given will generally lead the quite inexperienced man, moreover, to survey two lines at least, as it is but right that it should, because his limits of error are so very wide. The unduly great importance attached to the minor details of alignment, distance, curvature, and rise and fall is responsible for much unnecessary surveying. In these details large differences very often exist, and how large they are can only be determined with any degree of precision by actual survey. But this is not so of traffic advantages, nor even of grades, nor do surveys help to develop the former.

1179. Even in the case of lines through difficult country, passing over one or more high summits and with no local traffic to consider, connecting terminals only, it will in general—although with not infrequent exceptions—be found that thorough and faithful reconnaissance will remove all doubt as to which is the proper route; many details, of course, requiring extensive examination. The lowest pass or passes are so commonly the only proper place for the line, that it may almost be said to be a law of nature, and the lowest pass can be determined with close approximation by the barometer and study of the drainage lines alone. The natural advantages of routes by the lowest pass result, not alone from its lowness, but from the fact that at such points natural causes have produced more manageable slopes, a greater proportion of good material, and a shorter distance to pass over before reaching the easier and more practicable country, affording favorable grades and cheap construction. The lines from Vera Cruz to the city of Mexico, described in Appendix C, are an example on an immense scale of the certainty with which a single general route can be picked out as alone worthy of instrumental examination, even in regions of the most extreme difficulty. Too much is trusted to surveys, because only the facts determined on survey are taken into consideration. As a rule, the general route may safely be selected in advance by reconnaissance merely. If the engineer be not able to select

wisely without surveys, he will be no better able after the surveys are completed. But to this rule there are exceptions.

1180. In such cases as Fig. 278, where there is a certain natural line which manages to miss three or four considerable towns, *CDEF*, lines running to and into those towns should always be run, as shown by the dotted lines, whether the other line is run or not. This is a very common case, because towns are apt to be in hollows or otherwise inconvenient of access, and a better grade, as well as cheaper right of way, can often be had by keeping away from them.

The dotted line in Fig. 278 is a very awkward looking line by comparison with the solid one, but if its comparative length be carefully measured, it will be found to differ but a

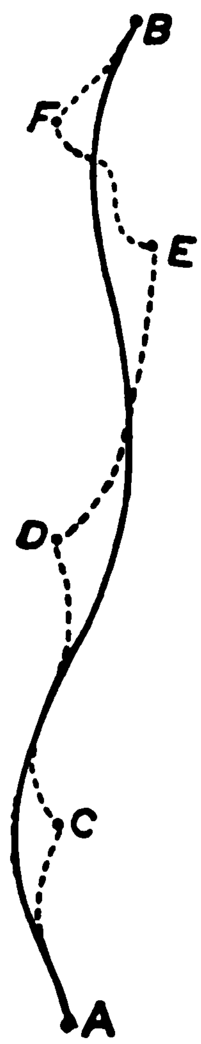

FIG. 278.

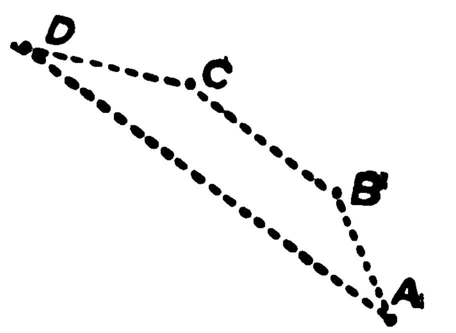

FIG. 279.

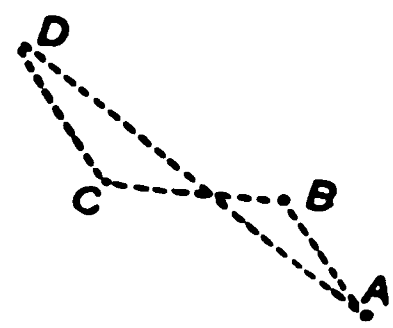

FIG. 280.

trifle in length while its operating advantages are materially greater, unless its grades should be decidely against it.

1181. In such cases as Figs. 279, 280, the line running through *BC* should likewise be always run. This is more likely to be done with Fig. 279 than with Fig. 280. In each the distances *AB*, *BC*, and *CD* are precisely the same; but the angular deviation from the desired direction is greater in Fig. 280, making it correspondingly repellent. By varying the intermediate distances, leaving the aggregate the same, much greater contrasts can be obtained, as the reader can find out in a rather instructive way with a piece of black thread and a few pins.

CHAPTER XXX.

THE FIELD-WORK OF SURVEYS.

1182. IN general, the economical manner of making surveys of a route which it has once been decided to survey, and which offers any appreciable difficulties, is as follows:

The surveys should be planned from the beginning with the idea that not less than three, generally four, and frequently five, successive lines will be run over the route for the purpose of fully completing the final location, viz.: An EXPLORATION line, FIRST PRELIMINARY, SECOND PRELIMINARY, FIRST LOCATION, FINAL LOCATION. The attempt to do with less than this on lines of any considerable difficulty is false economy; or rather, it is an attempt at economy which does not usually result in any real saving of either time or money, even in the mere direct cost of the survey, while it does seriously endanger the excellence of the completed work. Running what may appear to be so many lines does not necessarily involve devoting much more time to surveys, but only distributing the work somewhat differently.

1183. *First*, the EXPLORATION LINE, or what is popularly called a "shoo-fly" line, should be run as rapidly as possible over the entire route which it is contemplated will ultimately constitute the road. In the case of very long lines, circumstances may make it necessary to carry on and complete the surveys by sections, but this is to be regretted and avoided.

The purpose of this first line should be merely to get a general idea of the topography of the country, and especially of the gradients, and it should be passed over all alternate routes which it is proposed to survey later as they are encountered. No attempt to study the location in detail should be made, except to make sure that the line being passed over is certainly feasible, and probably on the most favorable ground in the vicinity, especially in respect to gradients.

For this line a mere compass line will not only answer as well, but is in general decidedly preferable to a transit line, except in easy open coun-

try, for reasons discussed in par. 1185. It gives a mere string of distances and elevations from which to construct a scheme of grades and lay out the line as a whole. The following line is not guided by it in any accurate way, nor is even a map of it to a large working scale generally worth the making.

The limit of speed will lie in the levelling, and accordingly two rodmen should be used if there be only one leveller, or better, two complete level parties (especially if the country is at all rough), to be jumped over each other's heads. This extra force does not expedite the work enough to pay if the levelling only were to be considered, but as the time of the whole party is to be considered, it does pay, and it is to some extent a safeguard against errors, as the levellers are not so hurried. Sometimes an extra man to keep notes, with two rodmen, may be preferable to two level parties.

A full-scale profile of the ordinary form may or may not be made: it will probably be a waste of time to make it for the entire distance; but a small scale profile, to about one tenth the usual horizontal scale and one fifth the usual vertical scale (par. 905), should by all means in all cases be made. Fig. 281 shows one form of such profile for a completed road, to a scale of about one inch per mile, as engraved, which was originally 4000 feet per inch, or ten times the usual profile scale. It is unnecessary to encumber a similar profile for location purposes with details of the minor structures.

Following this line comes—

1184. *Secondly,* THE PRELIMINARY LINE proper (which may be two successive lines), which is to serve as the basis for the final location. On this line, in all but very easy country, careful topography should be taken, and taken in the field, in the manner considered in Chap. XXXI. The purpose of the preliminary is to serve as a framework for this topography and the located line, and it is run to follow closely the ground where the location is likely to lie, as nearly as the eye can estimate it, using any angles which come handy for this purpose. Fig. 282 shows how *a very well located* preliminary is apt to lie with relation to the located line, being very close to it, and yet entirely independent of it. The average preliminary will diverge from the location more than that shown.

This line also may, without any serious disadvantage, and with certain considerable advantages, be a compass line, if any time is thereby saved to be devoted to more important matters. The only advantage of a transit line (and it is a slight one) is that it enables the map to be somewhat more accurately made. The located line does not coincide with

Numbers are those of Stations of 100 feet each.

FIG. 281.—EXAMPLE OF A CONDENSED PROFILE COVERING ABOUT SIX MILES OF LINE.

Original scales; horizontal, 4000 ft. per in; vertical, 150 ft. per in.

(This profile may be improved upon in the following respects: The grades might much better be indicated in rates per cent; the alignment by a succession of semicircles and tangents at the top or bottom of the profile; the structures by conventional signs immediately under the grade-line and at the correct distance below it; the length of side track and exact position of stations by proper marks.)

the preliminary at any point, unless by accident, nor is there any intention that it should, nor is the location checked by the preliminary, to any great extent, but by the profile and topography.

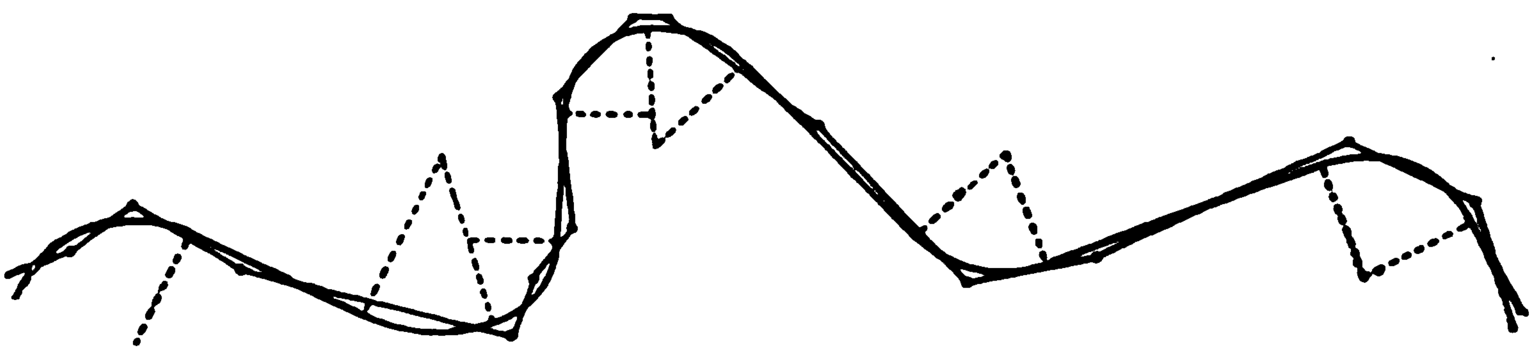

FIG. 282.—PRELIMINARY AND LOCATED LINE.

TRANSIT *vs.* COMPASS LINES.

1185. An unreasonable prejudice exists in the minds of some engineers against compass lines, because of a false assumption that, because there is a certain lack of precision in it, the work is therefore inaccurate. On the contrary, the chances of substantial accuracy in the final result, considered as a whole, are better with the compass than with a hasty transit line (it being assumed that no local attraction exists), since large cumulative errors cannot occur in the one case, while they can in the other. This is evident if we consider how the two lines are run.

A compass line, strictly so called, is run entirely by foresight, guided by the needle alone. The chief of party goes first, accompanied by the "back flag," who is now a front flag, and picks out the points to which to run (unless a straight line is being run, where the line is given from the instrument as soon as the compass has come to rest). The chainmen follow, the head chainman behind, chaining in a straight line as nearly as the eye can determine from the point where the instrument is standing toward the flag. As the line is sighted in by foresight this is near enough for all practical purposes, since more than two or three inches deviation is not probable.

The transitman, or rather compassman, is at the rear of the whole party, and simply takes the bearing of each line by the needle, or, if a given line is to be continued, gives the proper line to the flagman in advance as nearly as it can be determined from the needle. If a tree or other obstruction is met, the instrument is simply moved to the other side of it, placed on the same line prolonged as nearly as may be (it may be a foot or even two or three feet off), and reset to the same bearing. If accurately reset, it will give a line, not the same as the original, but parallel thereto. Usually there is a few minutes' error in each bearing to

one side or the other. On the other hand, when the line behind is visible, it is very common, even in running compass lines to run by back sight for considerable distances, as on a transit line, or at least to check the bearings thereby. This practice does not especially conduce to real accuracy, however, but rather the contrary.

1186. A transit line, on the other hand, is run entirely by back sight, from an accurate sight on a plug, and all angles are measured exactly by the vernier. It is very much more precise than a compass line, and is the only suitable method for running in location lines, and the only method now practised, although it was not used in the earlier days of railways. It has these disadvantages:

1. It requires the cutting away of all obstructions, or tedious offsets around them, thus causing great loss of time and needless destruction of vegetation.

2. Any error in measuring or laying off an angle is cumulative, or continued indefinitely in plotting the notes. To guard against this, the angles in well-conducted transit-work are always checked by the needle, but nevertheless this danger causes frequent annoyance in practice.

3. The angles measured are never used as such in properly conducted mapping, but have to be reconverted into bearings. This, however, is a small matter, and may and should be avoided in the manner described in par. 1242.

1187. On the other hand, there is this to be said for the transit line—that it is not unfrequently the case that no time is saved by using the compass instead of the transit, since the level limits the rate of progress in any case. When this is so, it is undoubtedly as well to run the more accurate line, and wherever there is danger of local attraction it is the only proper one to run. But it should be clearly recognized that the transit line is to be preferred only for these reasons, and that wherever they do not obtain, the true engineer will immediately adopt the compass instead. The not infrequent notion that the use of the compass is derogatory to his skill and unworthy of him, simply because it is less precise, is absurd. Under the doctrine of chances, which is as well established as the law of gravitation, the probable average error in a series of observations decreases as the square root of their number.* If in a single observation it be 10 ft., in 100 observations it will be only 1 ft. each, and in 10,000 observations only 0.1 ft. For all the legimate uses of preliminary lines (they are sometimes used illegitimately) such errors in no way detract from its value and utility.

* i.e., as the square root of their number increases.

1188. The writer has not found that, even when the imperfections of mapping are reduced as they should be by the use of large scales, the superior precision of the transit is of much practical moment, and he feels a preference for the use of the compass on preliminaries, other things being equal, believing that it is easier for all concerned, and that there is less danger of giving thought to splitting tacks with the cross-hairs which might better be given matters of importance. It is well for the locating engineer to be frequently reminded, especially in acquiring his training, that instrumental accuracy is not an end in location, as in ordinary surveying, but simply a means to an end; that a thoroughly excellent location may be made with the level and chain alone without other instruments, and that a bad line is not a whit better for being instrumentally precise. No angular or lineal error which is not great enough to affect the riding of the locomotive over the track is of ultimate importance, while on the other hand errors of judgment, or unwillingness to disturb an accurately run line with a "good" profile, are evils of great importance. As it is always easier and in the end less costly to be accurate than inaccurate, the good engineer always will be accurate in all essentials, but he will not waste time in attempting unnecessary precision which does not add appreciably to the final value of his work.

1189. The levels should, on the preliminary lines, be kept correct by checking on the exploration-line benches and re-running all doubtful sections, at any seeming cost to the progress of the survey. No time is saved in the end by doing otherwise. No time should be wasted in trying to keep the stationing continuous.

1190. Whenever the country becomes quite rough, and especially where a grade-line is to be fitted to the ground, the preliminary line should from the beginning be divided up into two by running a first and second preliminary. It might seem a better way of expressing the same truth to say that whenever it is found that any section of the preliminary does not come sufficiently near to where the final line will be, it should be run over; but that is not true, and that plan of conducting surveys is more likely to result in loss of time and bad work. The true way of conducting surveys, from beginning to end, is to recognize in the beginning where there is likely to be difficulty and to run additional preliminary lines COMPLETE over those sections, thus gaining opportunity for more careful study and more thorough knowledge. Even then, there will be occasions enough when it will be necessary to "back up" and correct false steps from time to time on all the lines, to doing which occasionally,

of course, it is not intended to object; but in cases where there seems more than an even chance that the "backing up" will be a large fraction of the advance, it is always good practice to give up from the first all idea of completing the preliminary work with one line.

1191. When two preliminaries are thus run in succession, they should in general be frequently tied together and plotted on the same sheets so as to give continuous topography, all errors in the plotting (which with good work should be small) being left in the tie-lines, and the angles and distances of the second preliminary not distorted to make a fit.

1192. In extreme cases, as in that shown in Fig. 216 and others, the difficulties of location are so great, for short distances, that all idea of determining the final location from lines must be abandoned, and a complete topographical study of the difficult section made, after the fashion of what was formerly customary on surveys for English railways. But such cases are very rare, and, in general, working from single lines is all-sufficient.

1193. *Thirdly.* THE LOCATION LINE.—This line also should in general be divided into two and done twice over, complete.

It will save time often and money always, and is the only safe way to insure good work, especially where it is necessary to entrust a part of the work to men of little experience. The first location should be made approximately correct as it goes along, by backing up to correct the more serious and evident defects, but it is far better that all minor changes and modifications should be merely studied and thought over as the first location advances, and that, after completing the first line and taking adequate cross-sections of it or of a considerable part of it, the party should be recalled to run the whole of it over again, aided by its plotted cross-sections.

1194. This results not only from the direct advantage of having the details of the whole line at once to study, but from the fact that the problem is studied more coolly and dispassionately, with the aid of more extended knowledge and experience (the whole party being now skilled in their work), and without that strong inducement to tolerate bad work and "let well enough alone" which is derived from the tedious and fretting process of "backing up." A little consideration of the weaknesses of human nature will make it clear why, for many reasons, this should be so; and the writer cannot urge too strongly that really good work cannot be otherwise secured, under the conditions which usually prevail. Unnecessarily sharp and frequent curvature will be left in the line; side-hill work on steep slopes will have its centre line a foot or two out of its

proper place, and be unnecessarily heavy; rock cuts will be run into to save fills, and many similar imperfections be left in the line, which are not, indeed, of great comparative moment to the line itself, since they do not injure its earning capacity, but which are often of serious moment to the temporary owners of the line, by increasing its first cost beyond the limits of their means, so that it finally passes out of their hands.

ORGANIZATION OF PARTY.

1195. A locating party should be full-handed, especially in the lower ranks. To do otherwise is false economy. The organization should in general be as follows:

1. *Chief of party*, with nothing to do except to keep his eyes open. Even in the easiest country it is mistaken economy to attempt to have him run the transit, and it is now rarely attempted.

2. *The transit party*, consisting of transitman, head and rear chainman, back-flag, stakeman, and, in wooded country, a superabundance of axemen. From four to eight can be advantageously used where there is much wood. At least one besides the stakeman is generally economy, even where there is no clearing.

3. *The level party*, consisting of leveller, rodman, and, in wooded country, one axeman and peg-maker. In open country this axeman is unnecessary; but, on the other hand, in such country, since the level limits the speed of the whole survey, two rodmen can generally be employed to advantage, since they expedite the work somewhat.

4. *The topographical party*, varying from one to three or four men, according to the country. This party is usually not full enough for true economy.

5. *The transportation and camp outfit*, in a full party usually consisting of a cook, and one or more teamsters, with a commissary, who looks after all camp movements and expenses.

Thus a fully-organized locating party in difficult country will often consist of as many as 20 or 24 men; but, on the other hand, in thickly-settled regions and easy country often not more than 8 or 10 are necessary.

RUNNING IN THE LOCATION.

1196. In smooth and nearly level regions the notes for the location line may be made up from the notes of the preliminary surveys, almost without mapping them at all, and certainly with very little topography.

Ordinarily, however, a narrow belt of topography is both expedient and necessary. If the preliminary work has been skilfully conducted, it will need to be but narrow. On this topography a "PAPER LOCATION" is made, in the manner we shall consider later; full notes of the projected alignment, and of the points of curve and tangency taken off, and a profile of the paper location made.

The purpose of the location field-work is, *first*, to put this paper location on the ground so as to afford at least as good a profile as the "paper" profile, and, *secondly*, to study the line thus put upon the ground in more detail than was possible before the precise position of the line had been so accurately fixed.

In running in the notes of such a paper location, the most experienced chief of party never expects that the notes can be followed in the field without some slight correction at almost every curve. The profile will be found to be running too high or too low; errors in the field-work and the topography will be discovered; new changes of alignment will suggest themselves, and in other ways changes will be made. Nevertheless, the correspondence in general will be very close; so much so that it will be difficult to distinguish the paper and actual location profile. They may both be wrong and bad, but they are apt to agree with each other quite closely.

1197. No new topography should be taken with this line, but instead of it cross-sections only, extending from 30 to 100 feet on each side, according to locality. These cross-sections should be plotted as closely together as clearness permits, WITH THE EVEN STATIONS AT UNIFORM DISTANCES APART, even at the expense of crowding the sections so that they overlap each other greatly, which does no particular harm. The character of the material, and especially the precise limits of the rock, should be carefully determined. Boring tools of many different forms (the simplest of which is the common post-augur) are readily obtained, by which it may be positively determined where the rock lies, at no great cost, and much perhaps needless expense saved. It is a very common thing to have shallow rock-cuts turn up in the bottom of excavations, which are always disproportionately expensive, and often might as well as not have been avoided altogether.

Aided by these cross-sections, the location should be carefully restudied, not by the construction parties, who have other things to think of and are often incompetent for the work, but by a location party who re-run the entire line complete. There will still be chances enough for the construction engineer to improve on it.

1198. This last work especially, and in fact all running of curves and tangents, is greatly facilitated by the use of a proper system of transition curves. What transition curves are, and why they can never be omitted if an easy-riding road is to be obtained, have been already stated (pars. 279–81), and the proper method of running them in is given in the field-book which follows this volume. It would lead us too far to attempt it in this. The nature of the advantage which they give in making a good location is this:

All transition curves, by whatever method they are run, must, from their very nature, have the form shown in Fig. 283. The actual tangent must lie parallel with and outside of (at a given offset from) what would be the tangent if the main curve were prolonged to include the whole angle turned. In all the systems of transition curves which have been put before the public by others than the writer, so far as he knows, these offsets are fixed, which makes running them in a considerable addition to the field-work, but even then they are likely to have a certain beneficial effect on the construction, for the reason that the curves of natural slopes generally ease themselves off in this manner.

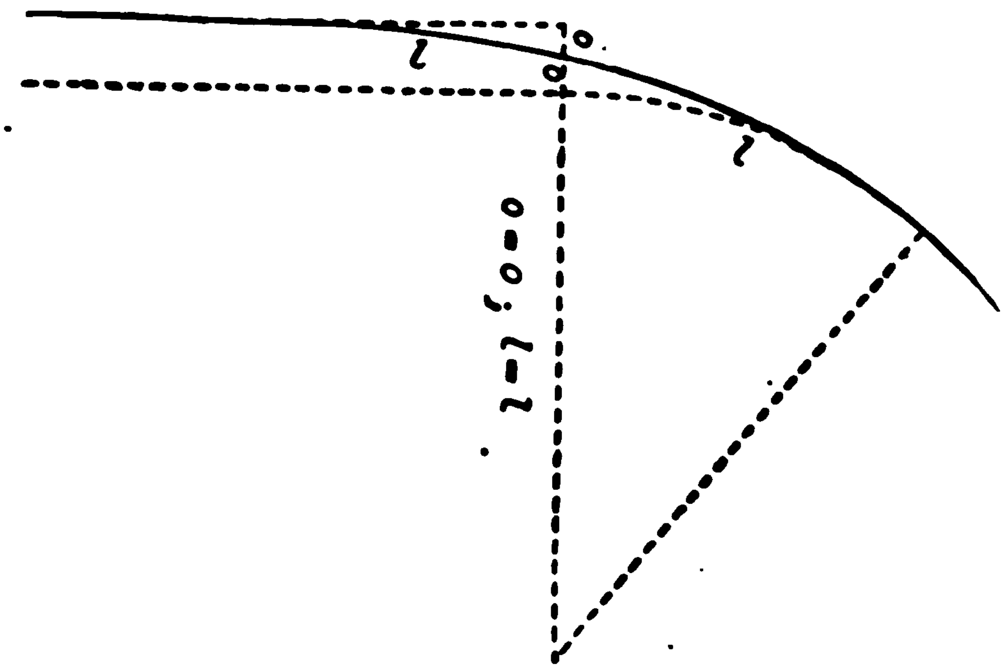

FIG. 283.—TYPICAL TRANSITION CURVE.

1199. But in any entirely satisfactory system of transition curves any offset, great or small, within wide limits, should be capable of use with any curve, because it will very materially add to the flexibility of the line and facilitate its adaptation to the topography. If we consider the transition curve as a cubic parabola, the only difference which the offset makes in the curve is to increase its length in proportion to the SQUARE ROOT of the offset, so that if the latter be four times as great the curve will be twice as long. In any case, the curve remains a cubic parabola, and is readily put in, either directly with the transit, as the line reaches it, by methods similar in their nature to, and quite as simple and easily remembered as, those for running circular arcs, or by offsets, after run-

ning in the full circular arc from an offsetted tangent, as indicated in Fig. 283.

The former of these methods is generally preferable for large offsets, and the latter for small. The immense advantage which the method gives for making the finer adjustments of the line may be made evident by one or two illustrations, but it should be remembered that the chief object of the curves is not to facilitate location, but to obtain a line which trains will run over smoothly.

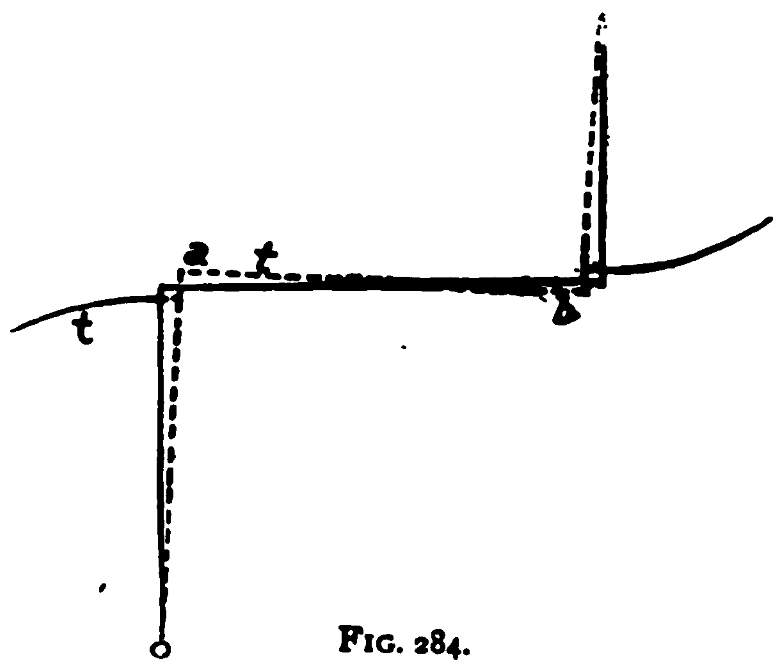

FIG. 284.

1200. EXAMPLE 1. It is found to be desirable to swing a located tangent, Fig. 284, in 2 ft. at *a* and out 3 ft. at *b*.

The angle between the old and new tangent can be at once calculated. Then the two adjacent curves must be extended (in Fig. 284—or cut off, had the change of tangent been in the other direction) by the same angle. This can be done at once; the offset determined by measure, whatever it may be, and the corresponding transition curve put in by offsets from the curve and the new tangent; or the tangent points *t* and *t* of the new curve may be determined and the transition curve run in by the transit.

1201. EXAMPLE 2. It is desired to take out a "broken-back" curve, Fig. 285. Governing points which it seems desirable the curve should pass through are *a* and *b*, at any offset from any point on the tangent.

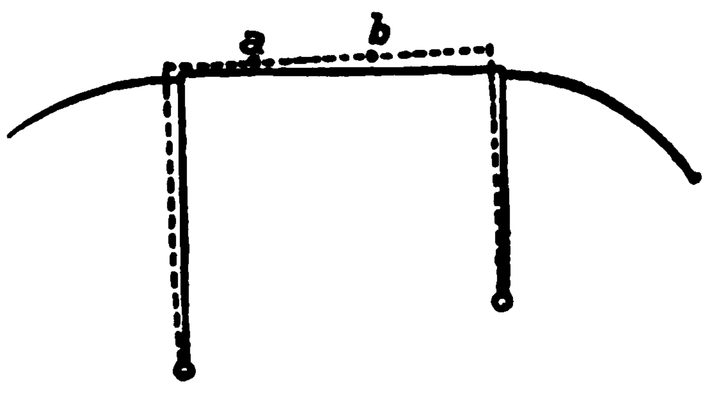

FIG. 285.

The angle between the new and old tangent can be calculated as before; the curves extended or reduced by an equal angle, the actual offsets measured, and the proper transition curves put in. If the change has been well planned and the conditions are at all favorable, the two curves will come very near to meeting at some point near the middle of the tangent.

If it leaves a little tangent between the two curves it will not greatly matter. The two desired ends will have been accomplished, viz.:

1. The two shocks to the train in entering and leaving the tangent will have been avoided.

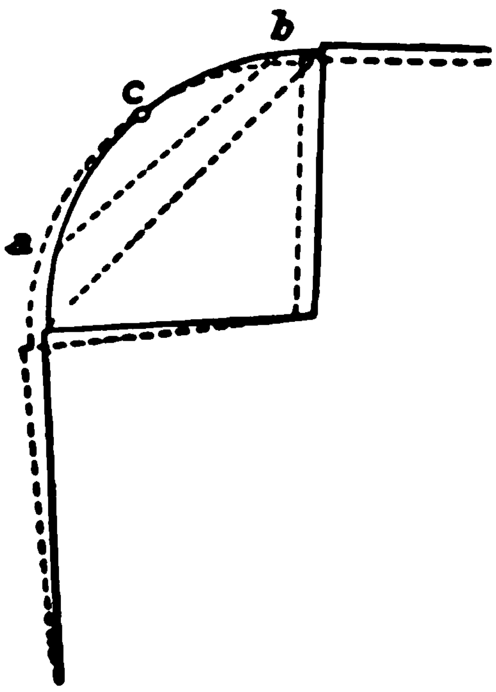

FIG. 286.

2. The ugly appearance of a broken-back curve, which, owing to the abrupt transition from curve to tangent, always has the appearance of being out of line and somewhat reversed, will have been corrected.

If the two transition curves of the required lengths for the offset chance to overlap each other even by a considerable distance it will not much matter. It simply introduces (for reasons which cannot be given here without discussing the whole theory of the curve) a short CIRCULAR ARC of very long radius between the two transition curves.

1202. EXAMPLE 3. A curve is found not to lie on precisely the right ground. It is desired to throw it out two feet at *a*, and in 3 feet at *b*, Fig. 286.

This implies that there will be a certain point *c*, at which the new and old curves will coincide. The whole curve, radii, centres and all, will be practically rotated around *c*. The distances *ca* and *cb* can be determined by the proportion

$$ca : cb :: \text{offset } a : \text{offset } b.$$

The angle of rotation is readily calculated by computing the change in position of the chord *ab*, and from these notes we may either start at *c*, and run in the new curve, or start at *a* or *b*, or compute the new positions of the original *P. C.* and *P. T.*

If the new curve is found to crowd too closely upon or to overlap the tangents we must change the latter also. This we do, however, entirely independent of the curve, if it appears desirable to do so; putting the tangent upon the ground which will suit it best, measuring the actual offset which the locations chosen give, and then putting in the corresponding transition curves.

1203. These examples will illustrate, as well as more, the peculiar advantage of transition curves, thus used; that they enable each part of the line to be studied and modified in detail, independently of the rest; and the new and old lines to be then connected together in what is at once the very best possible and the simplest possible way, without any of the puzzling geometrical problems and the confusing field-work which

are as apt to result from slight changes as great, if certain geometrically exact connections at all points of circular arcs are taken as essential.

Differences of offsets of 20 ft. or more are readily admissible under this plan, and in projecting location it is unnecessary to consider what the actual offsets will be. Figs. 208, 216, and others illustrate how this is done. The advantages of the method in such rough localities are evident from those engravings, and these advantages become even greater if one knows how to save unnecessary trouble in field-work, which will not tell beneficially in the final result.

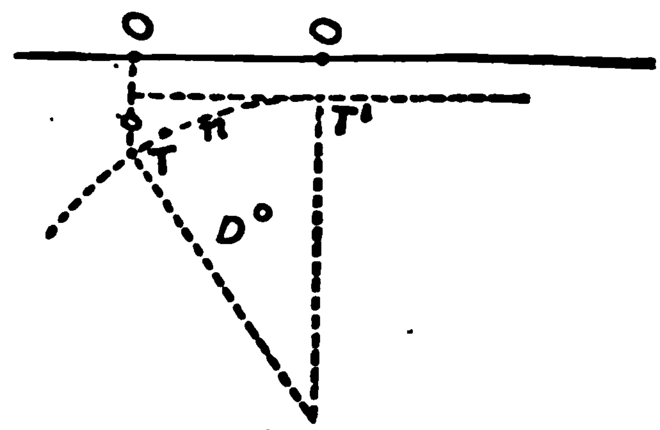

FIG. 287.

1204. As a single example, if one has a curve formerly terminating at T, Fig. 287, which is to be extended to T' in order to connect with the tangent OO;—to determine the offset O it is quite unnecessary to run in T' with a transit. The offset Oo to the old point T may be measured instead. Then will

$$O = Oo - o, \qquad \text{and ☞ } o = \tfrac{1}{8}n^2D,$$

in which D = the degree of the curve, n = the distance in stations from the tangent point T' to the point where the offset to the curve is desired, and O = the desired offset.

1205. This latter formula is one of the most useful of all location formulæ, being almost indispensable for the correct and expeditious conduct of field-work. It is closely approximate (in all cases sufficiently so for what is required) within the widest possible range of values of D and n, and it is one of the few formulæ which should be indelibly engraven in the memory of every locating engineer, ready for instant use. It applies equally well for offsets from one curve to another having a common tangent point, letting D = the difference in the degree of curvature.

CHAPTER XXXI.

TOPOGRAPHY: ITS USES AND ABUSE.

1206. TOPOGRAPHY, in the limited technical sense of the word which is given to it in railway location, is the representation upon a map by "contour lines" of the comparative or absolute elevations on the area covered by the map. In a broader and more literally correct sense, it includes the representation of all the details of the surface by any method whatever, including its form, character, and artificial structures.

Topography, in the broader sense, may be represented approximately either by hatchings or "hachures," or by washes of color. Very beautiful effects may be produced in this way by skilled and patient work, but the results are only of pictorial value, to give a general idea of the region, and are of no assistance for the details of location. Topography, when spoken of in connection with the latter, means an EXACT representation of the form of the surface, so that the elevation of any point can be determined from the map, and hence a line be drawn on the map and a profile of it called off, as well (barring a margin of error) as if the line had been run in, and levels run over it, in the field. Figs. 208, 216, and others are representations from actual practice of such maps, reduced photographically from the working scales.

1207. The nature of contour lines may be thus explained: Conceive a certain area, the topography of which is to be taken, to be entirely flooded with water. Conceive the level of the surface of this water to be lowered by a certain fixed distance, say ten feet at a time. At each lowering of the water a new shore-line would be developed: The contour lines are these imaginary shore-lines. If the slopes be very steep these successive shore-lines will be at small distances from each other horizontally. If the slopes be flat they will be at greater horizontal distances, and if the slopes are very flat they will be at very great distances apart, and only a few will appear on a moderate area. Thus the lower part of Fig. 288 shows a contour map of a slightly oblique cone, and the lower part of Fig. 289 a similar contour map of a hemisphere. In each case, if the nature of contour lines has been grasped, they enable the mind to form a very correct picture of the form of the surface.

1208. It will be obvious that working with such topographical maps has both advantages and disadvantages. The advantages are:

1. The eye is able to take in a large surface at once, with exact information as to the form of every part of it, and without those confusing optical illusions which result from looking at a natural surface horizontally instead of from above, and in successive bits instead of all at once.

FIG. 288. FIG. 289.

2. Various projects can be studied with great ease, and the effect of different changes considered at once. A curve can be struck in with a compass in a moment, and three or four different ones in as many different positions almost as quickly, each one of which would take perhaps a day's hard work to run in on the ground, with the chance after they were run that they would lie considerably out of the position intended.

3. By dotting on the grade-contour (pars. 1246–8) or line where the plane of the road-bed cuts the natural surface, it can be seen almost at once whether the alignment is as favorable as the topography permits, or not.

1209. Each one of these advantages is a great one. On the other hand the disadvantages of working from contours are:

1. The making of good contour maps is expensive—which is a very weak objection, even if their cost were much greater than it is.

2. It is difficult to insure accuracy.

3. They afford no evidence of material.

4. They do not impress upon the mind the magnitude of the works projected, as it does to study the actual surface.

5. They are of assistance only for doing the least important part of the work, making the first approximation to the detailed location of the line.

These and other difficulties which we shall shortly consider are likewise great and valid ones. They indicate what is the fact, that topography has both its uses and abuses, and which predominates is often the subject of heated discussion.

1210. In such discussions one is reminded of the old fable of the two knights who fell to fighting over the shield which seemed gold or silver according to the "point of view;" for the disputed question is emphatically one of the same kind. It is only by losing sight of one side or the other that one becomes a strong partisan of either view.

The difference between the two views, in fact, is more imaginary than real. On the one hand, there are no engineers of any standing or experience who believe that location offering any difficulties can be made to advantage in any other way than from topographical notes embodied in a more or less elaborate topographical map; while, on the other hand, there are no engineers of experience who would think of claiming that more topography than is really necessary for intelligently completing the location, and making sure that it is correct, should be taken.

The true question to be decided, therefore, is simply HOW MUCH topography should be taken, and where the line should be drawn. There is no such difference of opinion as would appear from an error into which many have fallen—an error which well shows how completely the views of those who take one side of this question are misapprehended by those who think they disagree with them;—that is to say, there is no class of engineers who attempt to make a final location assisted by the natural eyesight alone, or in any other way than by working from a preliminary line as a basis, which is intended to lie, and if skilfully run does lie, very close to the line on which the final location is placed, as in Fig. 282.

1211. To mark the limits of the debatable ground still more closely, it cannot be reasonably questioned (1) that in proportion to the skill of the engineer the preliminary line (often at difficult points, necessarily, the result of two or three trials) will approximate more and more closely to where the final location will ultimately lie; (2) that it should, and in general will, lie nearer than 300 or 400 feet as an outside limit; (3) that the placing of this preliminary line upon the ground is and must be

purely a matter of individual "eye for country" and good judgment; and (4) that the really vital and dangerous errors of location, the selection of the general route, the system of gradients, the going to or passing by the local towns, etc., etc., are committed, if committed at all, before any topography whatever has been taken, in locating this preliminary line; the usefulness of the topography beginning only after the more momentous question of WHERE TO PUT THE PRELIMINARY has been decided, and serving only for the more ready and perfect adjustment of details—details which have an important effect upon the cost of construction, indeed, but do not otherwise seriously modify the earning capacity of the line.

1212. The remaining ground for difference between extreme advocates of either view is this: The extreme believer in topography is indifferent to getting his preliminary very near to its ultimate location, looking upon 400 or 500 feet average distance apart as near enough, and takes or causes to be taken a wide belt of accurate topography to save the need of a new or a better preliminary. But the advocates of the other view say, "No; the engineer who can be trusted to put a preliminary line within even 500 feet of the true location can and ought to, in general, put it much nearer; or if not, it is cheaper to put a new line through still closer to the ultimate location than to take so wide a belt of topography. By one method or the other, the good engineer can and will bring the line so near to where his location should lie, that the topography which he will really need will be only a very narrow belt—usually no more than a few series of cross-sections, and hardly amounting to a topographical map at all."

1213. The truth lies between these two limits. Since the amount of topography ultimately needed and used (when its use is not abused by making it serve as a substitute for the careful placing of the preliminary) can be seen on any location map to be very little, covering a map all over with accurate topography is a sign of weakness and not of strength. On the other hand, accurate topographical contour lines for a reasonable and moderate distance on each side of the line are an immense assistance for the ready projection of lines, and at points can hardly be dispensed with. It is also an important truth that the usefulness of topography is not confined simply to that portion of it which is used to project the line adopted, but extends also to the portion which enables one to make sure that no other and better alignment might have been adopted. However confident an engineer may feel that he has in fact studied his work to the best of his ability, he owes it to himself and to

1217. 3. The best topographical maps which it is either expedient or, in general, possible to make, with the time, money, and men at command, cannot by any means, as is sometimes foolishly claimed, be relied on within a foot, nor even 5 or 10 feet, at critical points, especially if extending to any great width on each side. Over most of their area, if well made, they will be trustworthy, but minor irregularities of considerable importance, if nothing more than a few big boulders, get smoothed out of the map or misplaced or exaggerated, so that the only safe rule is to look on the first location, however carefully studied, as still open to much improvement—an expectation which will rarely be disappointed. But if frequent minor changes are to be made, much of the advantage of computing field-notes from a paper location so precisely as is often attempted is lost. It is not in fact good practice to do so.

1218. 4. To run in long stretches of location successfully without further topographical tests, but only the geometrical test of a "tie" to a preliminary, requires the nicest field and office work from the beginning to the end of the survey. It is, of course, only a question of degree. No one would advocate anything but good work of the kind, but it is obvious that less precision is required, if it is fully understood and expected that the paper location will be topographically tested throughout, than if it is expected to be, in the main, a finality. This saving of needed precision means some corresponding saving of time and money, which, as Mark Twain said of his profanity, "can then all be saved and devoted to some other end, where it will do more real and lasting good."

1219. Another objection, which is perhaps the strongest of all, against too great reliance on contour maps, is founded rather on the foibles of human nature than on any purely technical reason: It encourages a disposition in the higher engineering officers to throw the field-work of location into incompetent hands, and to assume to themselves the function of fixing the petty details of location, and hence (since the whole is only equal to the sum of all its parts) to control the whole location from their office chair, without giving to it that careful, thorough, and continued study on the ground which alone will qualify the ordinary man to wisely exercise such control. This practice works injuriously in several ways:

1. It deadens the perceptive faculties of the engineer in charge of the party and transforms him into a mere machine. He may, if an unusually skilful and faithful man, go over the paper line with a microscope and improve its details, but he will not be watching out for and thinking of the larger details, especially as—

2. The practice leads to the engagement of poorer men for the field-work; and

3. The engineer who puts in the paper location, and controls the work, never qualifies himself by familiarity with the ground to do well even that minor duty, and is so little in the field that the far more important end of avoiding the larger errors is not duly insured.

1220. The "conclusion of the whole matter" therefore is, that accurate topography for a certain narrow strip is a highly useful adjunct to practical location, which should never be omitted altogether and should generally be very carefully taken and studied; but that it is in no way a safeguard against anything but minor errors of location, and is not a safe nor expedient reliance for giving the last degree of perfection even to the details of alignment.

Great differences in natural aptitude for location exist, and among the strongest believers in the absolute necessity of elaborate topography may well be some who have less of this natural aptitude, and hence will not make very good use of the best of maps. In fact, although we should not allow this to prejudice us against topography, it is beyond doubt that those of least natural aptitude for location rely most on topography, and are the most helpless without it. On the other hand, those who have or think they have such aptitude may be led thereby to be over-confident, and commit errors which good topography would reveal to them. It is certain that the better natural qualifications a man has for the work the less topography he will take, because he will see in advance where it is and is not important. He will always take some, however, and what he does take will be correct.

1221. Another truth may appropriately be added here. It is easier to put a line, of some kind or other, on a topographical map than on the ground; but to do the best that the ground admits is almost as hard, and takes almost as much study and skill, on the contour map as on the ground. This the inexperienced projector, of good natural parts, will soon find out if, after having put in a paper location, which he thinks is very good, he will start in over again on the assumption that it is all very bad, and give two or three times more thought and care than before to finding out wherein it is bad. He will probably soon be satisfied that his assumption was correct, by finding his curvature and quantities simultaneously diminishing.

1222. There is a tendency in discussing this question, as in many others, to fall back upon the singular, yet in a sense natural, argument which seeks to defend some one way of doing things by showing that some of those who take

another way do work badly. On the one hand, we have pictured the "born engineer" spending days in fitting a bad line to the side of a hill with his "practised eye," when hours would have sufficed with the assistance of a little well-taken topography; and, on the other hand, a man studying over topographical maps of a line in the wrong place, missing the salient features, and perpetuating on the ground errors of the maps. Either picture may well be drawn from life, for out of a hundred men doing anything which requires skill, more than half will do it but indifferently well, a considerable fraction wretchedly ill, and only a small proportion thoroughly well. This fact insures a supply of ready weapons for supporting either side of any argument, yet it is strange that they should be so often chosen, since it is clear that they prove nothing. But as evidence of this inconclusive character seems sometimes to carry undue weight, we may add a few words further as to certain details.

1223. The fact that the actual profile of a line run from a "paper location" agrees so precisely with the latter that the two cannot be told apart, is no proof of the excellence of the system, for both profiles may be bad. It proves the geometrical excellence of the work, but it also proves, or tends to, that the whole process is too mechanical, unless the "paper location" has been at least so improved or modified in detail as to be distinguishable from the other.

1224. On the other hand, fixing the details of the alignment in the office, to be put on the ground by other men of less skill, while never a desirable, is not necessarily a wrong, way of doing things. We are often compelled to do, not what we would, but what we can. If there be but one skilled man to look after half a dozen parties, and perhaps look after other work as well, it is impossible that he should do much more than put the line on paper, and he is far more likely to project a good line in that way than an inexperienced man is to reach the same end, either on paper or on the ground, or both. When, however, one ceases to look on this practice as merely a necessary evil, and begins to look on it as an ideal state of things, so that on a difficult line it is "required" that the projected location should be "strictly followed" and "no cut-and-try permitted," as is sometimes done, then the abuse of topography—and a dangerous abuse, sure to waste more or less money—has begun. The better course in such cases is to require the engineers in the field to make the first projection, which is simply sent in for examination and revision if necessary, so as to compel them *to rely on their own intelligence and not on another's*, and especially to give an indication of the extent to which their own skill can be relied on. For if unequal to making a tolerably correct projection in the first instance, they will probably be still more unequal to the more responsible duty of putting in the final line.

1225. To mention one instance among many, of the evils of too great reliance on maps: an unusually accurate paper location, on a very steep side-hill, gave a beautiful profile, which no one could detect in the office to have any fault. The cut averaged about a foot, which was what prudence seemed to require,

1229. In rugged and broken topography, as where there is much rock and large scales are to be used, the third method, by cross-section rods, is much the best. These rods are in principle nothing more than a horizontal measuring-rod of a fixed length, sometimes 10 but better 12 ft., carrying a level bubble, so that it can be set exactly horizontal. This is carried by one assistant while another reads with a light vertical rod, *B*, Fig. 290, the rise or fall of the ground in the given distance. In practice, to prevent warping of the rod *A*, it is usually made in one of the forms shown in Fig. 291.

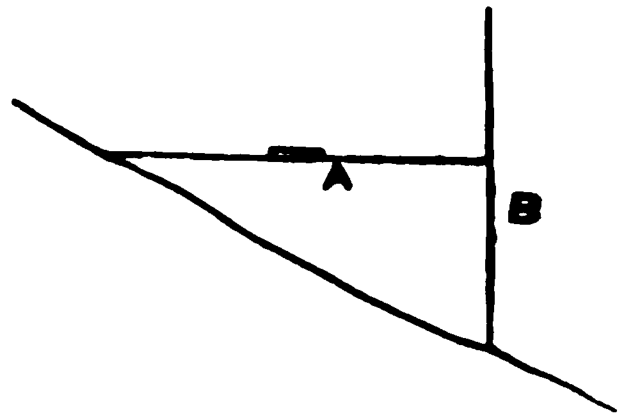

FIG. 290.

These rods are convenient to have with a locating party in rough country, and they are especially suitable for cross-sectioning a located line, but the process is much slower than any of the others specified, which are in general better for ordinary topography.

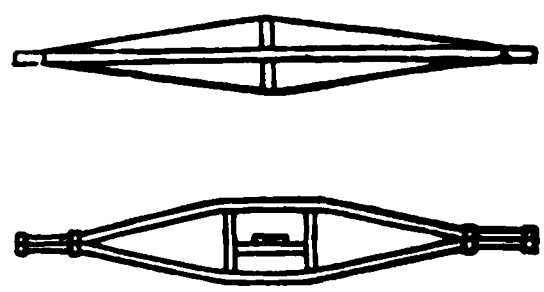

FIG. 291.

1230. A wise choice between the slope-level and hand-level methods, also, depends a good deal upon circumstances, and the character of the topography to be taken, although each method has its partisans who will rarely use any other. By the use of the altazimuth either method can be used at will, which is one of the distinguishing merits of that instrument. Much more depends, however, upon the individual skill of the topographer than upon the use of any particular method. Where the country is rough, with irregular slopes, the hand-level method is to be preferred, since it is more positive. Otherwise, the slope-level is best.

1231. The topography based on these slope-notes, by whatever method taken, SHOULD INVARIABLY BE DRAWN IN THE FIELD DIRECTLY UPON THE WORKING MAPS OF THE LINE, which should be the first and only direct use made of the cross-section notes. As a safeguard in case of doubt, the rodman may well keep a note-book record of them, but this should be strictly restricted to such use only. The habit of taking the cross-sections in the field and drawing in the topography in the office cannot be too strongly discouraged. It is certain to result in more or less imperfect work, as well as loss of time. After a little practice a skilled topographer ought to be able to keep up with a transit and level party without much difficulty, unless circumstances require a wide belt

of exact topography to be taken, when he should be furnished with a double cross-section party. The main requirement for doing work quickly and well is to train the eye and judgment so that needless cross-section work need not be done while yet taking all that is essential.

1232. The topographer is provided with a thin drawing-board, having a leather or oil-cloth pocket on the back, in which are carried the sheets, about 19 × 24 inches in size (par. 1240), on which the line has been plotted the night before, the stations marked off, and the elevation of each station and plus, as taken by the level, lightly pencilled on it. The topographer must thus work behind the level, but a good topographer will endeavor to keep very close up to it. One sheet at a time is pinned upon the board for use. A 6-in. scale, preferably of paper, lead pencils, and rubber complete his outfit. His two assistants (or four if need be) have nothing, necessarily, but tape and hand-level, with a small hatchet. A small compass for taking bearings is in general desirable.

1233. In taking cross-sections, the elevation of each station is given to the rodman (or has been previously taken off by him), and an offset measured off to a point, as indicated by the hand-level, where the contour next above or below the elevation of the given station falls. Thus, in Fig. 292, with contours 10 ft. apart, elevation of station 704.2, contour 710 is 5.8 ft. above it, and contour 700 4.2 ft. below it. The distance out in which the ground rises or falls these amounts should in general, on rough ground, be directly determined, and then the distances to a succession of other points, falling 5 ft. at a time, as far out as accurate topography is taken. On smoother country a little trouble may be saved as below spoken of.

FIG. 292.

The points where the contours cut the centre-line are also, at the same time, noted by the topographer. He then makes a light pencil guess at the course of the contour lines ahead, and passes, perhaps, two stations ahead, to "17.4," Fig. 292, and repeats the process, the rodmen in the mean time cross-sectioning the intermediate station if it seems

essential, or more properly speaking, unless it seems unessential. Until the topographer has acquired well-founded confidence by practice he will save nothing by taking chances, and be liable to throw discredit on his work.

Here the previous guesses are checked by the cross-sections and the course of the contours sketched in backward, exactly and finally, and lightly ahead, with further pencilled guesses. In this way the topographer trains his eye and his hand, and forms an idea of where accuracy is and is not essential, and if he be once properly instructed, and has a capable assistant, it is not at all difficult to take a mile or two of topography a day in ordinary country. When he has to take more than 200 to 300 ft. on each side it becomes a different matter, and progress is much slower.

1234. If slopes are determined by a slope-level it is still simpler work. A scale is then constructed, showing for a series of different slopes from $1°$ to $20°$, the horizontal distance apart of 10-ft. contours, which is $10 \times \cot S$. From this the contours can be put down upon the map at once, at the proper distances apart, or as far out as the slopes are taken.

1235. Time is lost and accuracy sacrificed in many surveys by using too small scales. The standard working scale may be said to be 400 feet per inch, or $\frac{1}{5000}$ (nearly the same thing) when the metre is used; but this scale is adhered to far too strictly. In rough country it should be at once doubled, and in very rough country should be increased to 100 ft. per in. or $\frac{1}{1000}$ ($83\frac{1}{3}$ ft. per in.). These latter are the only suitable scales when there is any considerable proportion of rock-work. It rather saves work in taking topography, adds but little to the drafting work, and adds immensely to the practical value of the maps when made.

1236. The following cautions will assist in taking topography correctly:

1. One contour line can never run into another and either disappear altogether or afterwards depart from it, in the manner shown at *AA*, Fig. 293, but must always be everywhere a separate, distinct, and continuous line until it either runs off the map or closes on itself so as to form an irregular ring or circle, as at *B*, Fig. 293.

There is, indeed, one case in which two or a dozen contours may so run together into a single line, viz., when an absolutely vertical slope is to be represented. There is even a possible case—that of an overhanging cliff—in which the contour lines may cross over each other and back again, as in Fig. 294. But both of these cases are so rare, although they do occur, that it is unnecessary to consider them as normal types of topography.

Fig. 293.

1237. 2. It is impossible for a contour line to split into two parts which sooner or later reunite again, in the manner shown in Fig. 295. It is a frequent error of young topographers, and an immediate evidence of inexperience, to believe the contrary. It is indeed theoretically conceivable that a surface should have such form as to make a sketch like Fig. 295 topographically correct. Thus, if we imagine it to be a representation of the crest of a hill, it MIGHT come to so sharp and regular a ridge, if made of dressed stone for example, that only a single mathematical line at the peak or ridge of the slope should appear above the water, and yet that the ridge should so appear above the water for a considerable distance, being precisely level, and should at a certain point swell out into the "island" *AA*. But practically, with natural surfaces as they actually exist, this is plainly impossible, and the true method of representing the natural surface, which is erroneously presented in Fig. 295, would be as shown in Figs. 208, 216.

FIG. 294.

FIG. 295.

1238. Topography, more largely than almost any other mechanical detail of engineering work, is a matter of practice. The young engineer who ends his first day's work at topography discouraged, with but a few stations taken, and that so badly taken as to be worthless, can by even a few days' determined effort to understand it, and do what he does do well, learn to go over as much ground as an ordinary transit party. It is a valuable drill for cultivating the faculties most needed for location, and good topographers generally make the best chiefs of party. In country at all rough the topographer fills the most responsible position on the party below its chief, and he should so rank.*

* The art of taking topography should be taught in schools more thoroughly than it is. There is no better drill for cultivating those faculties of mind which make the engineer.

CHAPTER XXXII.

MAPPING AND PROJECTING LOCATION.

1239. BUT two methods of mapping railroad surveys are to be commended, which are:

1. *For large-scale working maps:* plotting lines by bearings with a large paper protractor and parallel ruler.

2. *For small-scale maps:* by latitudes and departures.

Plotting lines of any length by laying off successive angles—a favorite way of laboriously making a bad map among inexperienced men—should never under any circumstances be permitted. All work should be plotted by bearings from a constant North and South line, which is transferred from sheet to sheet by prolongation or with a parallel ruler. Cumulative errors are thus avoided.

1240. Except in cases where fully 80 per cent of a line is tangent, and there is little topographical detail, a survey-line should never be plotted on long strips or rolls of paper, but always on small sheets, about 19 x 24 inches in size, or larger if there be little curvature and topography—say 19 x 36 inches. These sheets are added one after another as the plotting progresses, lapping one side or corner always *under* the preceding sheet, and giving its axis any random direction, compared with the other, which will best serve to keep the centre line of the survey in the middle of the sheets, as shown in Fig. 296. The two sheets are pinned together with thumb-tacks, and two or three X marks made at the lap, so that they can be replaced at any time in exactly the same position.

A North and South base-line should then be laid down the full length of the sheet, nearly in its middle, and a consecutive number for the sheet and the name of the line pencilled on, always in the same corner.

1241. The large paper protractor should then be laid down in the middle of the sheet on the North and South lines, from a clearly-marked permanent centre-point, and the computed or actual bearings of ALL the lines which are likely to fall on the sheet laid off at once. If omissions are discovered, the same process should be repeated; lightly

pencilling in the degrees and minutes of each bearing laid off, and permitting the points thus marked to remain permanently, except as they interfere with the mapping. Should any subsequent error be discovered, they may then all be checked at once, saving much time.

With a good parallel ruler (not the cheap and poor ones which are most used, but a heavy metal rule about 18 inches long), or, failing that, a couple of triangles, it is then but a few moments' work to transfer each bearing in succession to its proper point, draw in the line, and plot its length. The angles should then be roughly checked with a small protractor to guard against the large errors which are alone likely to occur. The bearing of each line and the plus at each angle should then be pencilled on.

Every station should then be pricked off and indicated by a light check-mark, and every fifth station should be numbered.

Opposite each station on a diagonal line should then be lightly pencilled in the elevation, and also the elevation of any pluses taken. The sheets are now ready to turn over to the topographer.

This work should be done every night. It takes but a short time after a little practice. The lines may be inked in on rainy days or at any convenient time. The centre line should be in red.

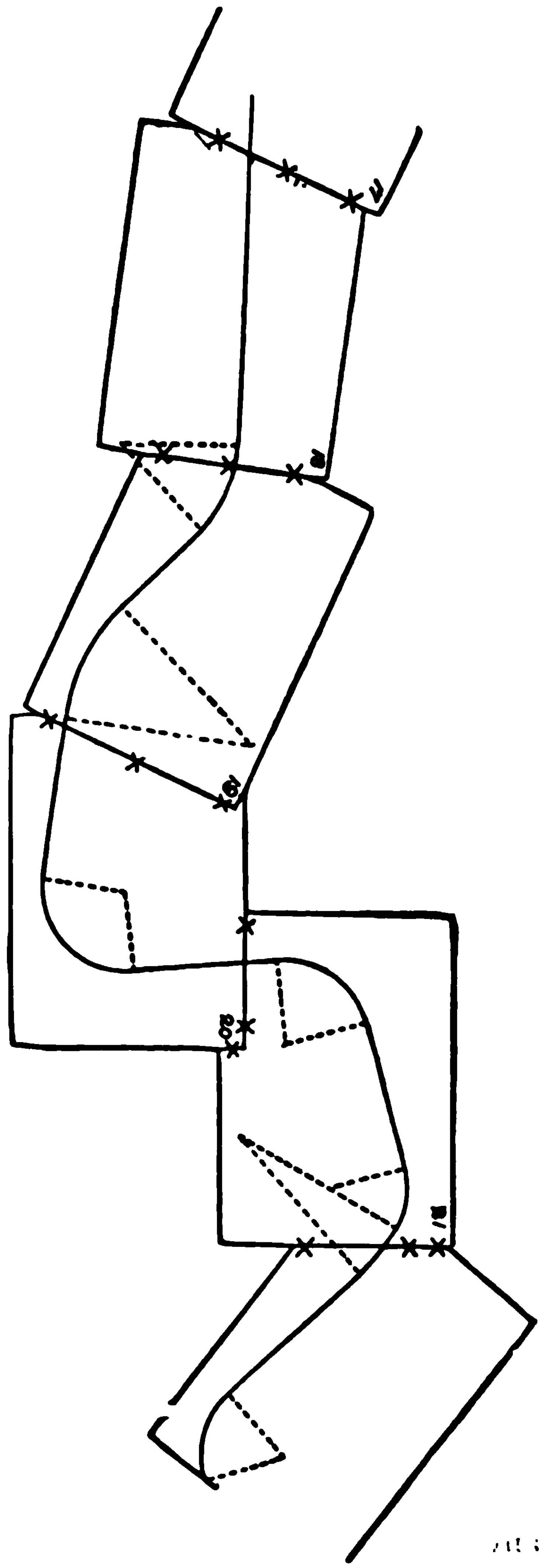

Fig. 296.

1242. For the same reason that plotting should be done from bearings, it is well to do all the transit

work, on preliminary lines at least, by reading BEARINGS instead of ANGLES from the vernier. In starting the survey the vernier is set at 0, and the lower limb clamped on a North and South line, or as near to it as possible. Unclamping the upper limb, we may then read the bearing of the line either with the compass or the vernier, and the two should approximately correspond. Retaining the verniers at the same reading for taking a back-sight at the next angle, and unclamping above to take the next sight, we obtain the bearing of the new line, likewise either by the compass or the vernier—the one approximate, the other exact. Thus we may continue throughout the survey, with the advantage (1) that we can check our work at any time by simply dropping the needle, since the needle and vernier readings should always correspond, and (2) that our "computed bearings" are already computed. We should work, however, by 180° on each side of the North point, and not be troubled by the transition from N. E. to S. E. This is the best way to do in any case, and it is easy to read the needle so.

1243. In inking in the topography, every fifth line should in all cases be made heavier or a different color. Black or brown for every fifth line, and brown or orange for the intermediates, does very well. Where possible, contours should only be five feet apart, although ten feet is usual. The values of every fifth line should be frequently written on them, in rows one above the other, preferably by leaving a gap in the line for inserting the figures, or otherwise by writing them directly over and across the line. Much of the prejudice against working with contour topography arises from the prevalent neglect of these simple directions, which seem almost too simple to mention. Such a map as Fig. 297, for example, is an abomination. It reflects just discredit on any engineer to turn in one in that condition, which makes it almost worthless to the engineer and incomprehensible to the mere observer. It should be finished up as shown in Fig. 298.

A light case, provided with three or four drawers of the proper size to hold the sheets, should be provided for field use. Light-yellow detail paper makes very good sheets, and is less trying to the eyes than white.

1244. Experience has clearly shown this system of mapping survey-lines to be far better than any other. Its advantages are:

1. But a small amount of paper is in use at once in plotting, while any number of sheets that there is table-room for may be put together if desired.

2. A very small table is all-sufficient.

3. No time need be lost in studying how to keep the line on the paper, or in rubbing out, or in pasting on extensions.

4. The map need not be covered over with prolonged lines for laying off angles, but only the actual length needed is drawn.

5. Great accuracy is secured without effort, and cumulative errors are impossible. If an error is made on one sheet it in no way injuriously affects the work on the adjacent sheets, except that two of them will have to be re-matched.

6. If matched properly the greatest precision is possible in laying them together again whenever desired. For all practical purposes they are as a single sheet.

7. There is no waste paper, and the line is always in the middle of what is used, readily accessible for office work. The awkwardness of working with wide rolls is entirely saved.

8. The paper is never rolled, but always flat and clean, in good condition for working on.

9. For projecting location, the ease with which any part of the line desired can be worked with, without annoyance from what is not wanted, and from change of scale due to rolling, gives it very great advantage.

10. The maps are readily stowed away in dust-tight boxes or drawers, and in very small compass, instead of taking up a great deal of room and getting into a practically unserviceable condition in a short time, as rolled maps usually do.

1245. For making small-scale maps, plotting by LATITUDES AND DEPARTURES is the most satisfactory way. The latitudes and departures should not be computed, however (or the labor would be prohibitory), but read off mechanically from a diagram similar to Fig. 299, which shows the principle of an apparatus for the purpose devised by Mr. Chas. Francis, Chief of Office on the Pacific Branch of the Mexican Central Railway. Any one can readily make it. The base is a sheet of accurate cross-section paper, 10 or 20 squares per inch, on which angles are accurately laid off, either around the edge, as shown, or on a circular arc of as large a

FIG. 299.

radius as possible. Values are given to the lines from zero to 100 or more. The straight-edge is laid off with the same scale.

We have then only to set the edge of the straight-edge at the angle corresponding to any bearing; place a needle-point or sharp pencil at the point on it representing the length of a given line, and we read off from the sheet below, at once, latitudes and departures for the line. Latitudes and departures for miles of line can thus be called off and tabulated in a day by two men, and the absolute position of every point on the survey, by rectangular coördinates from any fixed origin, determined once for all. From these notes as many or as few points can be transferred to the map as seems desirable, according to its scale, and the remainder sketched in. When several alternate lines are to be mapped together this method is especially useful, as the trouble of closing accurately is so greatly reduced.

PROJECTING LOCATION.

1246. To make a really good projection on a topographical map involves a great deal of work and study, and errors are almost as easy as they are on the ground. In fact the writer has no belief that any one ever projected a location on paper which could not be materially improved by study on the ground.

The most difficult case is projecting a final grade-line in which curve compensation is to be introduced as it advances. In very difficult country a first projection on an estimated average "straight" grade-line is often advantageous, saving time and giving a better final result because of the double study. The lower (dotted) spiral of Fig. 216 was projected in this way.

The projection should begin at the summit or other fixed point which the line must make. Assuming a starting-point and elevation, take in a pair of dividers the distance on the map which the given grade-line takes to fall 10 ft., or better yet, 5 ft. When curve compensation is introduced this distance will be different on a tangent and on every curve, and should be laid off on a strip of paper so that the dividers can be set and reset without trouble.

With the dividers thus set, step off a distance of 10 or 12 inches on the map, following as nearly as may be where it is thought the line will lie. On favorable topography this will be very closely along the GRADE-CONTOUR, or line where the plane of the grade strikes the natural surface. In that case we can step off quite a distance at once, steppin

down a contour or half-contour at a time, and marking by a small cross-mark where the grade-line crosses each.

1247. The grade-contour should then be very lightly pencilled in, and a curve or two, or a long tangent and the beginning of one curve, projected. Then, setting the dividers for the proper distance for a fall of 1, 2, or 5 ft. on the given curve or tangent, and starting from the fixed point, step along the projected location to the first point of curve and determine and write down its elevation to the nearest foot and tenth; paying no attention as yet to stationing, but simply to determining points where the grade-line reaches certain even elevations, and to determining the grade at the points of curve.

Having reached a curve from a tangent, reset the dividers for the proper distance for the given fall on the curve; start from the *P. C.* correctly by straddling the dividers over it according to its fractional elevation; step around the curve to the *P. T.*, and determine and lightly note its elevation. Reset the dividers for the next tangent or curve, and so on to the end of the section projected.

1248. Then return and correct the grade-contour according to the precise points at which the elevation of each contour or half-contour is reached on the actual projection, sketch every bit of it in, and see if the projection corresponds to the corrected grade-contour as well as is possible. Consider everything: the material (above all); the surface slope; the water-ways; whether the line should be preferably in cut or fill, whether the tangent or the centre of a curve cannot be slightly changed so as to fit the grade-contour better, or avoid a rock-cut; whether the form of the gulches is correctly represented and there is not a crossing point slightly more favorable above or below, which the topography does not clearly show; whether the tangent cannot be broken up by a slight curve and save work which will be more conspicuous on the ground than on the map; or, on the other hand, whether the line cannot be thrown out here and in there, so as to take out curvature and yet give as good a profile. Probably some little modification, at least, will be at once seen to be desirable, and the whole work will have to be done over, perhaps three or four times. If not, it may be for the time being left behind.

1249. A short stretch more should now be projected in the same manner as before, and now only will it be possible to give proper study to the first section; for the whole relations of the line to the ground cannot be taken in until the projection is complete for a considerable distance on each side of the point studied. It is now more likely than before that modifications will suggest themselves in the first section. The

reader who is quite satisfied with his first or second or third trial may justly fear that he is doing bad work. The projection in Fig. 216, for example, while good enough for an approximation, is by no means good for a final one, being capable of considerable improvement at several points.

After completing several miles the whole should be studied over again, and corrections unnoticed before are pretty sure to suggest themselves. Very often long stretches of the grade can be raised or lowered somewhat to advantage, at the expense of a slight break. It is difficult to point out every danger in advance, but it is a fact that men will differ in their projections almost as much as in field location, and the most obvious improvements will not suggest themselves until some one else points them out. Without an accurate personal knowledge of the ground, it is folly for any one to attempt to make a really good final projection, although contour maps have the great negative merit that glaring errors or general incompetency may be detected at sight by any one of experience.

Before the projection is considered final the corrected grade-contour should be made exactly right, and sketched in clearly and complete. It is very bad practice to sketch in only certain grade-points. A great check against error is thus lost.

1250. The line should now be stationed and a profile and field-notes called off. The latter are readily made up, since the length and degree of each curve is known, but they should be checked and corrected throughout by determining the bearings of every projected tangent from the original North and South line. Except when errors are seen to be compensatory the bearings thus read will be more trustworthy than the stepped-off lengths of the curves, and the latter should be modified to correspond.

1251. Curves may be projected either (1) by compasses, (2) by wooden, rubber, or metal curves, or (3) by a curve-protractor made on a large clear sheet of isinglass by scratching on the curves and rubbing ink in the scratches. The latter is a very convenient and desirable adjunct to the work, but not essential when the radii are not too large for compasses. With cut curves it is far more important. The writer personally prefers a pair of compasses to anything else when the radii admit of their use. The transition curves should be projected at the same time as the curves by drawing in the latter not quite tangent to the tangents, but at a slight offset to them, as in Figs. 208 and 216. What this precise offset may be does not matter. It may vary from 0.5 to 3.0 or 4.0 feet per degree of curve.

1252. Having made the profile, the GRADES should be put on it. Re-

member in putting grades on a profile that it is a great deal easier to stretch a thread to cover two or three feet of a profile than to execute with shovel and crow-bar the work which it calls for. Long shallow cuts are generally a mistake of judgment. The grade should rather be broken and thrown up into fill. As a rule, apices in grade-lines should never meet on a fill nor a hollow in them appear in a cut, since the extra depth of the cut or height of the fill is so much work thrown away in order to do a bad thing—bring grade-lines to a sharp intersection; but there are exceptions as respects fills, when it is desirable (as it always is) to give abundant water-way for streams without carrying the whole fill on too high a bank. It is a common error of inexperienced projectors to lay the grade-line too near to the supposed high-water mark. It is not worth while to take chances, and it should be several feet above all the apparent possibilities.

1253. It is always desirable, except on steep side-hills, to have the fills exceed the cuts. Heavy fills can be gotten at from a good many points, or temporarily trestled and filled by train, but large cuts are very apt to delay progress (they are generally the last work finished), and give trouble for maintenance later. Long, low fills should never be laid out to average less than two feet high. The temporary economy is a dear one. Grades can in general be laid out just as well as not at some even rate and starting from some even station, but the trouble often taken to this end is perhaps rather worse than thrown away, as it is a simple matter to compute the grade elevations, and economy is very apt to be sacrificed to no real advantage. Full allowance for vertical curves should be made as the work progresses and the grades for stations carefully looked after, especially in projecting long grades. Table 125, page 388, will facilitate doing so. The original grades should be studied over and revised, aided by the cross-sections of the final location. It is costly business to attempt to make the latter without accurate knowledge of the material under the surface, but this trouble is too frequently not taken. Simple boring and drilling appliances for investigating the material now exist in plenty, and the expense is very slight. Whenever and wherever there is danger of striking rock beneath the surface, there is little excuse for not determining its depth and limits, as it can often be avoided with ease.

1254. Provided with the profile and field-notes of the paper location the final location is proceeded with. The profile is kept close up to the transit, and the precision of the work as compared with the projection checked mainly by it. A few tie-notes with the preliminary are usually

taken off for each day's work, but it is not worth while to attach much weight to them. The question is only: Does the line as run on the ground give as good a profile as was expected and desired, and can any improvements be made in it? That chief of party is not a very good one who will not see many improvements as he progresses. Aided by the system of transition curves referred to in the previous chapter, these changes are rapidly made; but if there be any doubt at all about them, they should be left for a later revision. In fact, the better way is always to run the whole location over twice (par. 1193). The money spent will be well invested.

CHAPTER XXXIII.

THE ESTIMATION OF QUANTITIES.

1255. THE purpose of preliminary estimates is, *first*, to arrive at an approximate idea of the cost of the work; *secondly*, to compare alternate lines together; and *thirdly*, to assist in fixing the grades. For neither of these purposes is any great exactitude necessary, especially if there is certainty of having the quantities at least large enough. For estimating the cost of the work an excess of two or three per cent is rather an advantage. For comparing alternate lines the error, whatever it is, will make no difference unless there are causes why it should exist on one line and not on the other. For fixing grade-lines a slight percentage of error is equally unimportant, since it is rarely good engineering, under modern methods of construction, to attempt any very exact balance of cut and fill, the fill being always laid out in excess, and long cuts avoided as much as possible. The only exceptions to this rule are when both the cuts and fills are short and heavy, so that the haul will not be long, or on a steep side-slope, so that throwing the line out to decrease the cuts will increase the fills, or *vice versa*. Even then the possibility of using temporary or permanent trestles, the size of water-ways required, and the differences in classification will ordinarily have more effect on where the line is laid than the mere question of balancing the profile.

1256. For these reasons it is an absurd waste of time to use the prismoidal formula, or any other method but that of averaging end-areas, for making preliminary estimates, and this method should be used in the simplest way of all—that of determining centre-heights directly from the profile, unless the ground is quite rough and irregular. In that case, especially if the material be rock, plotted cross-sections may appear desirable.

In working merely from the profile centre-heights, without taking the trouble to compute them, there is a certain lack of precision which on an individual solid may introduce a considerable error, but we introduce no *tendency* to error in either direction. Our readings are as likely to be too great as too small, and when that is so we know from the theory of

probabilities that if the average error on each individual solid be 1, with no tendency to either excess or deficit, the probable net error per solid on 1000 such solids will be only 0.0316 cubic yards, and on 10,000 solids only 0.01 cubic yards. Thus there is no real objection to working from a well-made profile for any preliminary purpose.

1257. The nature of the error in the method of computing by averaging end-areas is this: The error increases as the square of the difference in centre-height, and is not in the least affected by the absolute volume of the solid. The heavier the work, therefore, or the less the sudden changes of profile, the less the proportionate error. That cut is an unusual one in which the error is more than 5 per cent, and that section of road would be very unusual on which the error was more than 1 per cent, and this error is always in excess. There are indeed certain possible solids in which the error will be in deficiency, and certain others (those whose width on top is the same while the centre-heights differ, or *vice versa*) in which the end-area method is precisely correct, while certain methods by the prismoidal formula which appear much more exact will give a deficiency; but except on perhaps one solid in a thousand, averaging end-areas always gives an excess of volume.

1258. All methods of computing volume by first transforming the end sections into equivalent level-sections introduce a constant tendency to deficiency, and for that and other reasons are a worse than useless labor, far simpler methods giving a more accurate result. The proper method of computing earth-work in construction is to compute by end-areas only, and then at any later time when convenience serves, to determine prismoidal corrections for those solids which need it only, which are those differing by more than two or three feet in centre-height. These corrections are then added together for each cut or section and deducted in gross from the end-area volume. The reasons which make this method at once the simplest and the most accurate of all, and the evidence from experience that it is so, are given at length in the writer's treatise on the computation of earth-work, referred to elsewhere in this volume, and, so far as he knows, are given nowhere else.

1259. In computing quantities from profiles for preliminary purposes the cut or fill should, as a rule, be assumed to terminate at the nearest half-station to where it actually does terminate, as shown in Fig. 300, whether its actual length be a little more or less. This introduces another element of slight uncertainty, but it is justified by the fact, which it is sometimes difficult for young engineers to realize, that the end of a cut makes a very small part of its total volume, so that very

trifling errors in the centre-heights at the middle of the cut will have far more effect. Moreover, as the error is as likely to be one way as another, it will be in the end compensatory, and no good end will be attained from the considerable extra labor of taking account of such details, unless the material is rock, and not always then, except in the final adjustment of the line.

The centre-heights are then read off at each station and the corresponding quantities determined. This is in effect equivalent to assuming that the actual solid in Fig. 300 may be transformed into the series of prisms bisected by the dotted lines.

FIG. 300.
[Showing the manner in which a profile cut is assumed to be transformed into equivalent prisms in making preliminary estimates.]

1260. It is not usual nor necessary, in preliminary estimates of earth, to make any part of the estimate for fractional stations. When necessary it is allowed for by taking the centre-heights a little higher or lower, as is also, in fact, any excess or deficiency in the length of the end section. In this way, with a little practice, closely approximate results to what the most careful work will give can be readily obtained. There can be no better practice for the student than to determine this practically.

1261. One source of error must be allowed for when it exists, however —the SURFACE SLOPE. This may be done either by using a coefficient to multiply the quantities when obtained, or by working from a diagram, like those devised by the writer, which give quantities at once for any surface slope. When the surface slope is level or under 10°, a table of level-section quantities may be conveniently used, or, still better, plotted as a diagram, as in those of the writer, and the successive quantities taken off by an odometer or on a strip of paper. The trouble and chance of error in addition is thus saved.

1262. In ROCK-WORK, or wherever these methods are not accurate enough, by far the better way is to plot the surface, draw in the road-bed and slopes with a template, and determine the areas with a planimeter, which is a very rapid, simple, and accurate method. Before the final

location is regarded as complete, it is in every way desirable that such sections should be plotted complete for the entire line and carefully studied.

1263. CULVERTS.—It is always a mistake to make separate estimations of each of the minor masonry structures. It is but two or three hours' work to construct a diagram on a single sheet of cross-section paper, which will enable the quantities for any standard type of culvert to be read off at once for any given centre-height, to a tenth of a cubic yard if desired, but the nearest cubic yard is sufficiently precise for the requirements. The surface slopes would make a material difference with the length of these structures, except that when the surface slope is steep it is rarely good practice to lay a culvert in the deepest hollow of a gulch. It may usually be placed somewhat higher and at one side, and often well up toward sub-grade, with very great advantage and economy, the only important point being to absolutely secure the lower end of the culvert against wash, which is readily done. Therefore, if a culvert be taken as the equivalent of one under the deepest centre fill with a level surface slope, it will ordinarily be sufficient. If not, it can be taken as much deeper as seems necessary.

1264. To construct the diagram, the volume of any box or arch culvert whatever (assuming it to be level) is expressed by the equation

$$v = fH + C,$$

in which $H =$ the centre height, $f =$ a coefficient depending on the cross-section of the main body of the culvert, and $C =$ a constant (which may be either plus or minus), which includes the modifying effect on volume of the ends of the culverts. To substitute actual values in the equation for any given type of culvert: Compute its volume complete with an average depth of foundation, under any height of fill from the natural surface—say 10 feet. Compute also the addition to its volume by lengthening it 3 feet (with $1\frac{1}{2}$ to 1 side slopes), or by whatever other length is added to the culvert by increasing the fill 1 foot. We then have values of v, f, and H to substitute in the equation, and C can be determined at once.

Such a diagram has another value than merely to save labor. It keeps before the mind the proportionate quantities in culverts of different sizes, although if this should lead to using smaller ones it would ordinarily be unfortunate. No dry work should be estimated for if cement is reasonably accessible. It is costly economy.

1265. BRIDGE PIERS.—Any bridge pier may be resolved into certain

parts independent of height; a rectangular solid varying directly with height, and a pyramid or cone. In other words, its equation of volume is of the form

$$v = fH + f'H^2 + C,$$

with values of letters as above. Numerical values may likewise be determined in the same way. With a batter of ½ inch per foot, the value of f', for volumes in cubic yards, will be only .00103. For a pier 10 ft. high this gives 1.03 cubic yds. as due to the batter; for a pier 100 ft. high, 1030 cubic yards.

1266. BRIDGE ABUTMENTS AND OPEN CULVERTS may have their volume expressed for constructing a diagram in precisely the same way, as may also pile or other foundations. It may not save any great amount of labor to do this, but it does furnish a check against errors in single computations, and is information which it is very convenient to have ready for instant reference.

1267. WOODEN TRESTLES are cheap affairs. The effort should be to estimate them liberally, but it is quite unnecessary in a preliminary estimate to waste time on a careful design, merely for the purpose of getting quantities.

In any wooden trestle, the caps and all the floor system above it, as also the minimum length of sill and all wooden parts below it, are directly as the length of the structure and independent of its height. The same is true of the cost of digging foundations, and the piling or masonry if used (as one or the other always should be).

At a certain distance below the cap, say 10 feet, there is a system of longitudinal, transverse, and diagonal ties and sway-braces running the entire length of the structure on a line about 10 feet below the caps, and (constructively) a certain addition to the length of the sill. All this may be expressed at so much per lineal foot on a horizontal line 10 feet below the grade-line.

Ten feet farther down there is a similar system, nearly duplicating the first, but a little larger, which may be all expressed at so much per lineal foot on a horizontal line 20 feet (or whatever the distance may be) below the grade-line.

So we may proceed until we have provided for the highest trestles likely to occur on the line of the given type, and we shall have expressed the feet board measure in any width in an equation of the following form:

$$Ft.\ B.\ M. = fL + f'L' + f''L'' + \text{etc.},$$

in which L, L', L'' = the respective lengths of the structure on the grade-line and on parallel lines 10, 20, 30 feet, etc., below it, and f, f', f'' = the corresponding measurement per lineal foot.

1268. The length of each of these lines below the grade-line ought, in theory, to be measured a little short on the profile to allow for any bents which may extend below one system and not quite down to another, but such nicety may be neglected. At the bottom of the trestle there will be an irregular area of greater or less extent. To include this in the estimate, transform it by eye into a rectangle 10 feet high and of equal area. Any one familiar with the construction of trestles will do this with great accuracy; and the results of this method, in which no account is taken of the particular number or position of bents, come surprisingly close to the ultimate measurement, as the writer has tested on many structures.

1269. Trestles should invariably be built with side stringers and ties about 12 ft. long, capped with a guard rail, as a safeguard against derailed trains, foot-passengers caught on the structure by a train, and the insidious effect of decay, as well as for its material addition to the strength of the structure even when new. "Split" stringers, breaking joints with each other, are invariably used in good practice, and split caps and sills boxed into the posts and bolted through make a far stiffer, better, and more easily renewable structure than the common form of mortise joints. "Cluster-bent" trestles made of 8 x 8 inch timber are the best for high structures.

The ends of all trestles and bridges should be protected by Latimer's rerailing safety frogs, a cheap cast-iron watchman which may be relied upon to put derailed wheels back upon the track, if not too far displaced, as has been proven by many instances.

1270. IRON TRESTLES.—Iron trestles may be estimated in much the same way as wooden trestles, and it is of practical value to do so to bring out how little the height of trestles has to do with their weight or cost,—a fact which, if it be fully realized and taken advantage of, may often be an immense assistance in obtaining a favorable line, by enabling it to be carried high above what are apt to be the most serious obstacles—the deep gorges.

Iron trestles, for some occult reason, are usually planned for bents 30 feet apart, each successive pair of bents being braced together into a kind of pier. Sometimes the intermediate spans are made 45 or 60 feet, and occasionally the bents are 60 feet apart, continuously. Sometimes the intermediate spans are increased to 100 or more feet.

1271. However these details are varied, there is wonderfully little difference in the total weight of the structure, which usually comes out much the same, barring a slight percentage. as if the simple type of 30-foot bents had been used throughout. What is gained in the bents is lost in the floor-system, or *vice versa*. This is strikingly illustrated even in so widely different a structure from the ordinary trestle as the Kentucky River bridge. The total weight of iron corresponds very closely with what would have been required to cross the gorge with a trestle with 30-ft. bents—not equally safe by any means, but of the same average weight per lineal and vertical foot as in the minor structures on the same road, built to sustain the same rolling load; so that in estimating structures for large and small gorges, by the same rule, we do not go far astray.

1272. This fact has led Mr. Geo. H. Pegram to propose the following formula for the weight of iron trestles, which he states that he has found to give close results when tested on a considerable number of actual structures:

Wt. in lbs. $= (3L + 2H)$ 110 for Mogul engines and 1820 lbs. per ft.; in which $L =$ the total length of the structure between centres of end-pins and $H =$ the sum of the total bent heights from top of masonry pedestal to top of columns, taken as 30 feet apart, whatever they may actually be. For Consolidation engines we may take $W = (3L + 2H)$ 125 to 130.

These formulæ give the total shipping weight of iron, and will ordinarily approximate within 5 to 10 per cent. They will be most in error (too small) for very large structures.

1273. To this estimate is to be added the timber-floor system and the pedestals. The pedestals are usually of the best quality of cut stone masonry, and on the Cincinnati Southern Railway, where all such details were very carefully looked after, averaged 1.6 cubic yards per lineal foot of trestle and ranged from 4 to 8 ft. high, above the natural surface. The floor system is readily estimated according to the design adopted, which should include plenty of timber.

On the Cincinnati Southern Railway (Mogul rolling-load, which proved too small almost before the road was opened) the average contract prices for viaducts were $25 per foot horizontal and $10 per foot vertical, including the floor. Adding to this the cost of masonry pedestals, we have, by a similar method of estimation to that recommended for wooden trestles:

Per foot horizontal at grade-line......................	$40 00
Per foot horizontal at intervals of 10-ft. below grade....	3 33

1274. We may see from this method of expressing the cost more clearly than otherwise how little the height of trestles has to do with

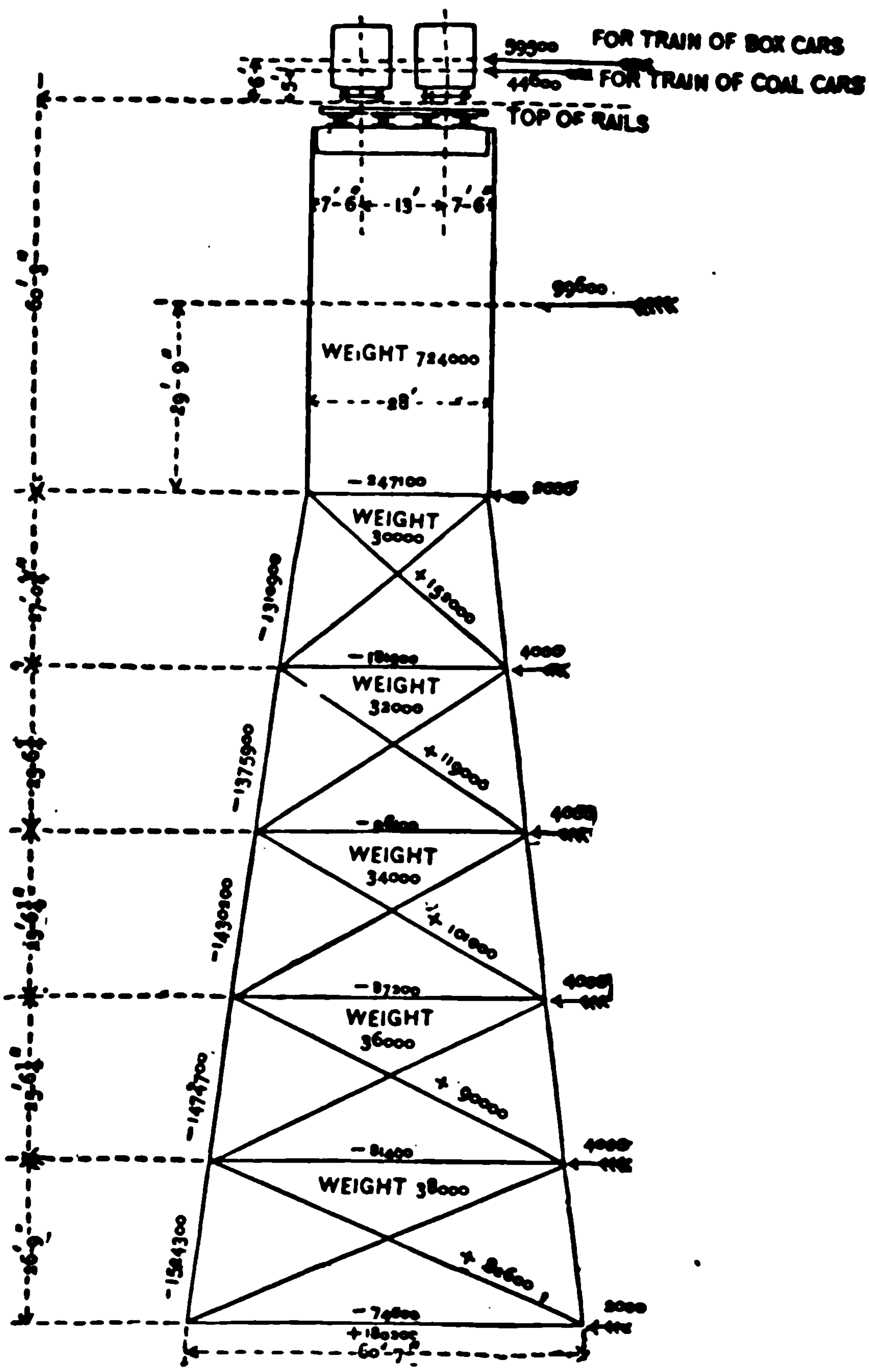

FIG. 301.—MAIN PIER OF NIAGARA CANTILEVER BRIDGE, SHOWING THE SLIGHT EFFECT OF HEIGHT ON THE TOTAL COST OF THE STRUCTURE.

TOTAL WEIGHT OF STRUCTURE.

Span, 248 ft. (2920 lbs. per ft.), ...	724,000 lbs.
Pier, 130 ft. 4 in. (1304 lbs. per ft.), ...	170,000 "
Total of pier and cantilever span, ...	894,000 lbs.
Additional per ft. extra height, about, ... or ⅛ of one per cent.	1,500 "

their cost. Singularly enough, it appears from comparisons of the contract prices on that road that it has more effect on the cost per foot horizontal than per foot vertical, which latter were very little affected; in part, no doubt, because erection is much more expensive per pound with low trestles. Fig. 301 will show how little the height has to do with the cost of even the largest structures.

1275. It is probable that pedestals of very superior concrete would be cheaper as well as better than masonry. One difficulty in the use of concrete, which is a very serious one with masonry also, is that under the usual form of contract the contractor furnishes his own cement. He is therefore under a constant temptation to skimp the work in that vital detail, both in quantity and quality. The true way is for the company to purchase its own cement, furnish it to the contractor liberally, and require him to use it so. He will then be as anxious to make the work good in that respect as he is now to make it poor. Much dispute and inspecting annoyances will thus be saved, the cost of the work little if any increased, and its quality materially benefited.

1276. BRIDGES.—In Fig. 247, page 767, there has already been given a diagram prepared by the writer, mainly from the formulæ determined by George H. Pegram, C.E., and given in a paper before the American Society of Civil Engineers. In addition to what is stated in connection with the diagram, it may be added that the West Shore specifications called for rolled I-beams up to 20 ft. span, plate girders from 20 to 50 feet, lattice girders from 50 to 75 ft., and thereafter pin-connected trusses. There was naturally a slight jump in passing from one to another. The weights of bridges of various spans were computed to be of first-class construction, without any additions of doubtful utility, so that while a bridge might weigh more than that given through some special excellence, it should not weigh much less. The following are the formulæ deduced by Mr. Pegram, in all of which

S = the span centre to centre of bed-plates or end-pins, as the case may be.

W = the total or "shipping" weight of iron or steel in pounds.

For iron bridges under 200 ft. span:

$$W = \left(75 + \frac{S}{a}\right) S \sqrt{S},$$

in which

$a = 7$ for Class T, Fig. 248, page 769.
$a = 9$ for Class C, " "
$a = 12$ for Class M, " "

For Class N, three fourths of the weight as given for Class T was taken—a very rough process.

For iron bridges over 200 ft. span:

$$W = \left(5 + \frac{S}{b}\right)S^2,$$

in which

$$b = 100 \text{ for Class C,}$$
$$b = 80 \text{ for Class T.}$$

For steel bridges over 300 ft. span:

$$W = cS^2,$$

in which

$$c = 6 \text{ for Class C,}$$
$$c = 6.7 \text{ for Class T.}$$

1277. The type of bridge assumed was as follows:

For spans below 75 ft.: deck-plate girder bridges, 8 ft. wide, connected with angle-iron bracing, and with cross-ties resting on the top chords.

Above 75 ft. up to 150 ft.: through-truss bridges, Pratt or single quadrangular trusses.

Over 150 ft.: Whipple or double quadrangular trusses.

The widths assumed were: For standard-gauge spans under 255 ft., 14 ft. in the clear; for 320-ft. span, 18 ft. centre to centre of trusses; for 420-ft. span, 21 ft. centre to centre, and for 520-ft. span, 25 feet centre to centre. The floors of the spans consisted of cross floor-beams at the panel points, with a line of iron stringers under each rail, except for spans over 300 ft., which had three lines of stringers.

Differences in depth affect the weight less than would be supposed. Thus in a 60-ft. girder span, for Class T, the difference in total weights between depths of 5 ft. and 5½ ft. was practically nothing, and for an 80-ft. girder span, calculated for Class C, with depths of 6 ft., 6½ ft., and 7 ft., the difference was less than 1 per cent. In a 180-ft. truss span, the difference in weights between depths of 26 and 28 ft. was less than 2 per cent.

In a 520 ft. steel span, for Class T, the difference in weight between a depth of 50 ft. and one of 58 ft., was about 3 per cent.; a depth of 56 ft. was finally taken in this case.

1278. Modifications for other conditions than those specified may be made as follows:

If wooden stringers are used, deduct 195 lbs. per ft. for Classes M. and C, 210 lbs. for Class T, and 140 lbs. for Class N.

For safety stringers add 100 lbs. per ft. for all classes.

For deck-truss bridges add 10 per cent, and for double-track bridges 90 per cent, to the formula weight.

Through-plate girder bridges will not differ materially from deck bridges in weight, where the cross-ties are made to serve as floor beams. When an iron stringer floor is used, it will be a close approximation to add 200 lbs. per foot to the weight given by the formula.

For bridges of less than 150 ft. span, the only part of the rolling load which affects the weight of the bridge greatly is the engine load. For spans of over 200 or 250 ft., an average of the engine and car-load per foot will come nearer to expressing the ratio by which the weight of the bridge is affected.

1279. The weight of a drawbridge, including turn-table, wheels and machinery to turn by hand, will be very nearly the same as for a fixed span of the same total length to carry the same live load. This rule is stated by Mr. Pegram to have been remarkably exact in tests on a number of drawbridges of 150 to 400 feet, both single and double track.

1280. The cost of bridges per pound is far from fixed for all classes of structures, but may be said to be made up as follows:

	Cts. per lb
1. Raw material, rolled and plate iron	$2\frac{1}{4}$ to 3
2. Work on same in shop	$\frac{5}{8}$ to $1\frac{1}{4}$
3. Transportation by rail	$\frac{1}{8}$ to $\frac{1}{2}$
4. Falseworks and erection	$\frac{1}{2}$ to 1
5. Profit and administration	$\frac{1}{2}$ to $1\frac{1}{4}$
Total	4 to 7

The lowest of these prices are sometimes cut under, especially in dull times and for large orders of a simple class of work. For example, on the Manhattan Elevated Railway, involving immense weights of a very simple class of work, contracts were let at 2 to 3 cents per pound, while, on the other hand, fat contracts at much higher rates than those given above are not uncommon; but these are fair averages for average work in moderately good and bad times.

It will be seen that only items 1 and 3 above, and not always even those, increase directly with the weight of the bridge. We may say in a general way that 10 per cent increase in weight, with its several times greater increase in safe rolling load, will mean not more than 5, or at most 6, per cent in the cost of the bridge to the company, and proportionately for greater or less differences of weight.

1281. Station buildings, yards, track and track-laying, and many other minor details of construction, must likewise be included in any complete estimate, but to consider them here would lead us too far from our subject, which has had to do with those details only which are connected with and affected by the location of the road.

In all such details, it has been intended to go far enough, and not too far, to at least fairly prepare the patient reader to make a decent approximation to the true economy of alignment. To do more than this can only be a happy accident with any one. To do less than this the writer hopes he may have rendered unnecessary. He has not spared his own labor to do so, and for wherein he may have fallen short he can only say with the heroine of "A Winter's Tale:" "I speak as my understanding instructs me, and as mine honesty puts it to utterance."

APPENDICES.

APPENDIX A.

EXPERIMENTS ON THE RESISTANCES OF ROLLING-STOCK.

[Made by the author on the Lake Shore & Michigan Southern Railway, at Cleveland, O., June-July, 1878. Abbreviated from Trans. Am. Soc. C. E., Feb., 1879.]

THE mode of test was by what may be termed the "drop test;" starting cars from a state of rest down a known grade, and deducing the resistances from the velocity acquired. The principle of this method has often been employed before, sometimes merely to determine comparative resistances, without attempting to measure their absolute amount, and sometimes to determine a single average resistance from the average velocity for the whole descent. In the present tests it was attempted, with entire success, to extend this method to the determination of a series of successive resistances at successive points (eleven in most cases) in the path of the vehicles, during which their velocity varied from 0 to 30 miles per hour. Great accuracy in time observations was necessary for this purpose, which was fully secured by the aid of electricity, so fully, in fact, that the margin for error in the latter half of the experiments is hardly more than $\frac{1}{10}$ lb. per ton. It must be added, however, that about half the tests were made before the apparatus was fully perfected, and are, hence, less minutely accurate, but the maximum errors in these latter can hardly exceed $\frac{1}{4}$ lb. per ton in any case, as will be evident from the record plates, and all errors of any kind in this mode of test are necessarily compensatory, any excess in one resistance causing a corresponding deficiency in the succeeding one, and *vice versa.*

It is believed that equal accuracy is unattainable by any other mode of test, since it is plain that every step in this process is free from any sensible source of error other than carelessness. The accelerating force (gravity) is uniformly applied, and exactly known from formulæ, without measurement. This force is necessarily all consumed (1) in overcoming the resistances to be measured, or (2) in communicating velocity. The amount of force represented by a given velocity is known by formulæ, without measurement, and the velocity itself is exactly recorded by

electricity, beside a synchronous record of seconds, from which intervals of time may be easily read off to $\frac{1}{20}$ second. Errors from carelessness in computation are always possible, but three checks existed against them: (1) All formulæ used were first tabulated by "constant differences;" (2) most of the resistances were computed independently by two distinct methods, and (3) all the computations, when completed, were plotted on the record diagrams (Plate IX.), and so many resistances were determined for each test at gradually increasing velocities, that any considerable error of computation revealed itself graphically. Finally, any errors which still occur are not cumulative, any excess in one resistance causing a corresponding deficiency in the next following, and *vice versa*.

The tests were made under as great a variety of conditions in respect to load, number of cars in a train, area of cross-section, etc., as it was possible to secure with the limited time at command, and give due certainty to each. This variety of conditions was secured in order to facilitate, as far as possible, one of the objects which was held especially in view, viz., a more correct separation than heretofore of the aggregate resistance *from velocity only* (excluding the normal axle-friction) into its constituent elements, air resistance, oscillatory resistance, etc. This object, it is thought, has been quite successfully attained, and with somewhat surprising results.

[The great length to which this volume has grown forbids the reproduction of the body of the paper, and those desiring to follow it are referred to the paper itself. The determination of the possible air resistance especially is believed to have been sufficiently exact to make it certain that it has less effect on the movement of trains than is commonly supposed. The following are the conclusions of the paper:]

SUMMARY.

We may summarize the various conclusions reached in the preceding paper as follows:

1st. The axle and rolling friction of empty freight cars may be taken as 6 lbs. per ton of 2000 lbs. The axle and rolling friction of coaches and loaded freight cars may be taken as 4 lbs. per ton. The fluctuations from these limits are small, rarely exceeding 1 lb. per ton in single cars, or $\frac{1}{4}$ to $\frac{1}{2}$ lb. per ton in a train.

2d. The initial resistance at the instant of starting is several times greater than this, and greater for loaded than for empty cars, being at least 18 lbs. per ton for loaded cars, and 14 lbs. per ton for empty cars, as an average, but fluctuating considerably. Its amount probably varies with the length of stop, according to unknown laws.

3d. Most of this initial resistance is almost wholly instantaneous, and consumes little power. Enough of it still remains, however, to increase the normal axle-friction in the first few car-lengths by at least 2 lbs. per ton.*

4th. The air resistance against such a surface as the end of a box car (about 80 sq. ft.) is less than ⅛ lb. per square foot at a velocity of 10 miles per hour, and (presumably) increases as the square of the velocity. The current estimates of this resistance (⅛ lb. to 1 lb. per square foot) are erroneous by from 250 to 500 per cent, when applied to surfaces of that size.

5th. About two thirds of the velocity resistance proper, excluding the normal axle-friction, is due to oscillation and concussion. The resistance due to this latter cause alone may be estimated at ⅛ lb. per ton at a velocity of 10 miles per hour, varying as the square of the velocity.

6th. The resistance of curves decreases materially with the velocity, and appears to be greater by a considerable percentage in the first 200 to 500 feet than on the rest of the curve.

7th. The resistance of a 1° curve is over 1 lb. per ton at a velocity of 12 miles per hour, and decreases to about ⅛ lb. per ton at a velocity of 22 miles per hour. The resistance of an 8° curve is over 8 lbs. per ton at a velocity of 9 miles per hour, and decreases to about 6⅛ lbs. per ton (probably) at a speed of 19 miles per hour.

8th. The average resistance of a 1° curve to 4-wheel trucks, having a 5-foot rigid wheel-base, and to 6-wheel trucks having a 10⅝-foot rigid wheel-base (except for the play of the boxes in the pedestal-jaws), appear to be almost identical.

9th. It appears possible that the act of coupling together cars by a loose link slightly decreases the axle-friction, and hence, presumably, the oscillating friction at high velocities. The average reduction observed from coupling four or five cars together appeared to be as much as ⅛ lb. per ton. [The tests appeared to indicate this, but the author now regards it as very doubtful.]

10th. There appear to be good grounds for suspecting that a slight superelevation of one rail on a tangent may have the effect of appreciably reducing the resistance to motion even at velocities of ten or twelve miles per hour.

* This, of course, does not include, nor in any way refer to, the additional power demanded to get up speed, which is 2 lbs. per ton to give a speed of 10 miles per hour in 3340 feet, or 4.5 lbs. per ton to give a speed of 15 miles per hour in the same distance.

11th. Roller-journals of various forms appear to be very effectual at velocities of o +, but lose nearly all their theoretical advantage as the velocity increases. Such journals appear to be more effective as the load is decreased, and reduce the resistances of empty horse cars by about one half.

12th. Forty-two-inch wheels seem to be even more effectual than theory would indicate in reducing extra friction.

13th. The equation of resistance for average trains (twenty cars) of loaded box cars may be taken, approximately, as

$$R = \frac{V^2}{130} + 4;$$

or, for trains of forty empty box cars,

$$R = \frac{V^2}{106} + 6.$$

The velocity resistances of flat cars increase somewhat more rapidly, being for twenty loaded flat cars $\frac{V^2}{113}$, and for forty empty flat cars $\frac{V^2}{81}$.

These formulæ are believed to be closely approximate up to velocities of thirty miles per hour. No tests were made at higher velocities.

14th. The coefficient of axle-friction is about .02 for loaded freight cars and passenger coaches at speeds of over five miles per hour, about .03 for empty freight cars, about .065 for horse cars, and about .12 for freight trucks without load. The coefficient is two to three times greater at the instant of starting. It decreases rapidly as the load per journal increases.

APPENDIX B.

EXPERIMENTS WITH NEW APPARATUS ON JOURNAL-FRICTION AT LOW VELOCITIES.

[A Paper by the author, read before the American Society of Civil Engineers, June 4, 1884. Abbreviated from Trans. Am. Soc. C. E., Dec., 1884.]

THE following experiments were undertaken by the writer in the winter of 1878, primarily to test the correctness, especially in respect to initial friction at low velocities, of a series of other tests of rolling-stock resistances (see Appendix A) made in a totally different manner, on the Lake Shore & Michigan Southern Railway, under the direction of Charles Paine, Member and ex-President of the Society, who kindly furnished the writer all necessary facilities.

The apparatus used is shown with sufficient clearness in Fig. 302. It is extremely cheap and simple, but fulfils its purpose as perfectly as could be desired, and is believed to be entirely novel. The axle *A* to be tested is placed in an ordinary lathe, having as great a variety of speeds as possible. The testing apparatus, as actually constructed, consisted of an oak beam, *C*, about 4″ × 4″ in size, and about 5 ft. long, carrying the compound lever, LL^1, each of which multiplies the load applied about 11 times, or, in the aggregate, 125 times. The yoke *E* encircles the axle and bears against the brass *B* underneath it, thus furnishing the necessary resistance to the action of the levers and throwing the same load upon the lower brass *B* as is imposed by the levers directly on the upper brass by transmission through the pin *D*, the latter being passed through a hole in the beam *C*. The pressure was transmitted to both the upper and the lower brass by suitable iron blocks (shown in the cut directly above and below the brasses), representing as nearly as might be the ordinary form of the top of a journal-box.

As thus constructed, it will be seen that the entire apparatus (when properly balanced, which is perfected by the light counterpoise *H*) is poised in unstable equilibrium on the axle *A*, and opposes no resistance to motion in either direction, except such as arises from friction. A very heavy load may be thrown on the bearings viz., 6000 lbs. (3000 lbs. on

each bearing) for every 24 lbs. of load, W placed on the extremity of the compound lever, but the only weight thrown upon the lathe-centres is the dead weight of the apparatus itself, which was kept constant at 205 lbs.

[Some further details are omitted here, and throughout the remainder of the paper.]

When the axle A is caused to revolve, the lever C is held stationary by the platform-scale, and it is obvious that the pressure produced upon

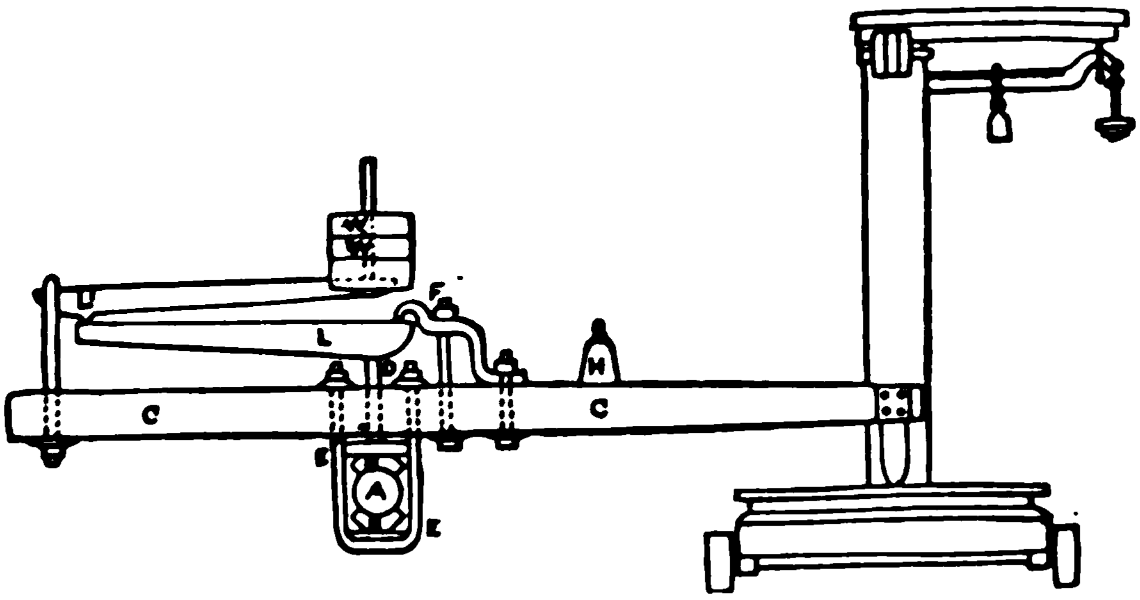

FIG. 302.—APPARATUS FOR TESTING JOURNAL-FRICTION IN A LATHE.

the scale furnishes an exact and direct measure of the journal-friction It was found in practice that this pressure, varying from 10 to 140 lbs., with the proportions actually adopted, could be weighed with as much delicacy and ease as if it were a material substance resting upon the platform of the scale. Under a given load and speed of journal the friction produced, although it did not remain absolutely stationary, varied so very little and so slowly that the beam of the scale would sometimes vibrate slowly and gently between the guards (sometimes touching the upper one and again returning to the lower, but for the most part touching neither) for 10 or 15 minutes at a time. On the other hand, when the brass was growing hot, by continuing the test for a considerable time the friction would continue to increase so that the scale-weight had to be continually moved; but the change was never so rapid but that it could be easily followed and studied with the scale, with an absolute certainty that the friction existing for the moment was being accurately weighed. The difference in friction caused by temperature was found to be very great, but in the absence of arrangements for accurately determining the temperature no very close results as to its precise effect were attempted.

As the failures in designing such apparatus are as instructive as the successes, it may be noted that the entire success of this apparatus depends upon the use of the platform-scale, or some equivalent device for weighing the strains, in which the measurement of the strains is as nearly as may be absolutely statical, no motion of the bearing whatever being necessary in order to express a variation of friction. It was at first attempted to use spring-scales to measure the friction, with the idea that variations of friction could be more delicately and readily read. The vibration which would almost instantly set up, seemed to indicate quick and great irregularities of friction, and absolutely forbade any useful indications from the readings.

It has been preferred in this paper to deal with resistances in pounds per ton, instead of the coefficient of friction, for two reasons:

1st. The determination of these resistances, and not investigations of the general laws of all friction, was the end in view in the experiments.

2d. The coefficient proper is a minute decimal, conveying no impression to the mind in itself, whereas resistances per ton are something that engineers are already familiar with, and being expressible with few digits and in integral numbers, the mind much more easily grasps and follows their relations to each other.

For the same reasons, the velocities here spoken of are miles per hour of train-speed. Multiplying the velocities given by 9 gives, very approximately, the journal-speed in feet per minute.

In the comparisons which follow, with various experiments the approximate formula, $R = 200C$, has been used to convert the recorded coefficients into pounds per ton. This is only correct when the diameter of a railroad journal is one-tenth the diameter of the wheel. In general, at the present time, it ranges from less than 9 to 9.6 times, the latter having been the ratio in the present test; so that the use of the approximate formula for converting coefficients obtained by others into pounds per ton gives a result about 4 per cent too small. In view of the fact, however, that these results differ 300 to 400 per cent from each other, in many cases under circumstances which seem to entitle them to equal credit, this error has not been deemed of moment, provided its existence be remembered.

The apparatus heretofore described is, when properly constructed, believed to possess every important advantage of the various testing machines in use, with some peculiarly its own. It is very light and cheap; the actual weights to be handled are very small, so that they are readily changed, and but little strain is produced on the machine; it can

be used in any ordinary lathe and with an ordinary platform scale, enough varieties of which can be obtained without special construction to satisfy every requirement; it is positive in its action throughout, and no delicate computation and construction of scales is necessary for its use; and it admits of any desired delicacy of readings by the simple substitution of more delicate scales. The common platform-scale of the shop where the tests were made was deemed sufficient in this instance, since the stresses actually weighed ranged so high that the error of observation from lack of delicacy in the scales could rarely exceed a fraction of one per cent. The axle was set very slightly eccentric, so as to imitate the effect of an imperfectly centred wheel. This probably somewhat increased the coefficient, although very slightly at the low speed used. The effect of end play in distributing lubricants was imitated by the occasional use of manual force. It was found possible to do this in great degree, and it was generally found to have a slight beneficial effect upon the coefficient, but only slight; especial pains was at all times taken to have the journal well lubricated before beginning each test. The journals and brasses were fairly well polished by use up to their average condition in service, but no more.

The tests made are shown in Table I. (omitted), and graphically in Fig. 303. Three different loads only were used in testing, corresponding as nearly as might be to the loads on bearings of a loaded car, empty car and truck alone. Each one of these it was designed to test a number of times at all the speeds which the lathe used admitted of. Whenever a bearing heated above 150° F. the tests were suspended and the bearings cooled, since no means had been provided for accurate measure of temperature. Each test, at any given speed and load, was continued for from 5 to even 30 minutes, when the bearings were cool, in order to be certain that it was a fair average. When the bearings were hot the tests were shorter, and the bearings were retained as nearly as might be at the same temperature by waiting a considerable interval between each test. During a test the resistance would generally fluctuate, slowly and gently, from 10 per cent to sometimes 20 per cent higher or lower than the average afterwards taken. This change was considered normal, and arose from no discernible cause. When the fluctuations were greater than this they were generally very much greater, and arose from heating of the bearings.

The intensity of the strain per sq. in. of journal (longitudinal section) is indicated graphically in this (and the following) diagrams, as follows :

Velocity — Miles per Hour.

FIG. 503.—DIAGRAM OF RESULTS OF TESTS BY THE AUTHOR.

Axle Friction — lbs. per Ton (2000 lbs)

NOTE.—*In all the diagrams below, as also in Fig. 303 giving results of the writer's tests, the journal-speed has been reduced to its equivalent train velocity in miles per hour and the coefficient of friction to its equivalent in pounds per ton tractive resistance to the locomotive.*

INTENSITY OF LOAD PER SQ. INCH INDICATED BY THICKNESS OF LINES.

Vel. Miles per hour.

FIG. 304.

Vel. Miles per hour

FIGS. 305, 306.

FIGS. 304–306. RESULTS OF MR. BEAUCHAMP TOWER'S TESTS, GIVING EFFECTS OF HIGH VELOCITY, VARIATION OF PRESSURE AND DIFFERENCES OF LUBRICATION UPON COEFFICIENT OF FRICTION.

FIG. 307.—COMPARATIVE RESULT OF PROF. R. H. THURSTON'S TESTS WITH SPERM OIL AND MR. BEAUCHAMP TOWER'S TESTS WITH SPERM BATH; THE LATTER INDICATED thus—o—o—o—

(The most notable fact in this diagram is, that while Thurston's and Tower's tests agree almost precisely, with sperm-oil, at 90° temperature and 100 lbs. per sq. in., increasing the pressure to 200 lbs. per sq. in. caused a marked *increase* of coefficient in Thurston's tests and an equally marked *decrease* in Tower's tests.)

DEDUCTION FROM THE TESTS.

(*Tons of* 2000 *lbs.*)

Initial Friction.—The writer's observations under this head were exceptionally complete, and the conclusions reached were as follows:

1. Friction at very low journal-speeds of 0 + is abnormally great, and more nearly constant than any other element of friction, under varying conditions of lubrication, load, and temperature. It varies from 18 to 24 lbs. per ton (coefficient, .09 to .12) for loads of from 30 to 280 lbs. per square inch. Within those limits it is not greatly modified by load or temperature.

2. This abnormal increase of friction is due solely to the *velocity of revolution* continuing unchanged so long as the velocity is unchanged, and returning to the same amount whenever the velocity is reduced to the same rate, barring exceptionally slight variations, probably due to

differences of lubrication and temperature. It is not appreciably affected by the fact that the journal may be just starting into motion, or is just coming to rest, or is temporarily reduced to a velocity of o + during continuous motion.

3. At velocities higher than o +, but still very low, the same general law obtains. The coefficient falls very slowly and regularly as velocity is increased, but is constantly more and more affected by differences of lubrication, load, and temperature.

4. A *very slight* excess of initial friction proper (varying from ¼ lb. to 2 lbs.) could generally (but not always) be observed over that which continued to exist at the nearest approach to a strictly infinitesimal velocity which it was possible to obtain. This difference was, by analogy, ascribed solely to the fact that the lowest continuous velocity attainable was not strictly infinitesimal, and the final conclusion was drawn that—

5. There is no such phenomenon in journal-friction as a *friction of rest*, or a *friction of quiescence*, in distinction from (i.e., differing in amount from) friction of motion at slow velocities, and due to the fact of quiescence. Consequently, the use of such a term, although convenient, is scientifically inaccurate, in that it ascribes the phenomenon to the wrong cause, and to a cause which is not necessary for its existence. The fact that friction of rest, as such, *appears* to exist, is due solely to the fact that no journal or other solid body can be *instantly* set into rapid motion by any force, however great. There must be a certain appreciable instant of time during which the velocity is infinitesimal and gradually increasing.

This interesting fact, which is believed to have been here observed for the first time (no other apparatus being known to have been used suitable for determining it), was determined with great completeness by many tests. Very slow motion could be produced at any time by revolving the driving-pulley of the lathe by hand when geared for a slow speed. With a little experience, the weight on the scale-beam could be placed in advance at a point which would be a trifle less than the initial friction proper, and (when properly placed) it would barely lift when motion first began, and then have to be moved back a notch or two only, to weigh the friction which continued to exist indefinitely. Similarly, when a test at comparatively high speed was about to be concluded, the scale-weight would be placed to measure the same pressure, or a little less, as existed in starting, and it was always found to indicate in stopping substantially the same friction as in starting. The same test was made by interrupting tests at speed, so as to give a continuous motion,

but to suddenly reduce the speed to o +. These tests were repeated again and again, with practically identical results.

Comparing these results with others, they agree very closely indeed with the writer's conclusions from the results of his gravity tests, as will be seen below:

"*Initial*" *Journal-friction* (i.e., at velocity of o +).

Writer's conclusions from journal tests, above, say..	19	to	25	lbs.	per	ton.
Writer's conclusions from gravity tests of rolling-stock (see Trans. Am. Soc. C. E., February, 1879), "at least"........	14	to	18	"	"	"
Prof. R. H. Thurston ("Friction and Lubrication," page 175), W. Va. oils........	22	to	28	"	"	"
Prof. R. H. Thurston ("Friction and Lubrication," page 175), sperm	14	to	28	"	"	"
Prof. R. H. Thurston ("Friction and Lubrication," page 175), lard........	14	to	22	"	"	"
Prof. Kimball (*Am. Jour. Sci.*, March, 1878, or Fr. and L., page 186)........	22	to	31	"	"	"
In addition, it may be noted that the writer has taken pains to observe with some care at various times that in ordinary service no railroad cars can start themselves from rest, nor can they, in general, be started without the use of much force, on a grade of .7 per cent (= 14 lbs. per ton, 36 ft. per mile), but that they will generally (but not always) start of themselves on a grade of 1.1 to 1.2 per cent (= 22 to 24 lbs. per ton, 58 to 63 ft. per mile), indicating an "initial" friction of........	20	to	24	"	"	"

These results agree wonderfully well with each other, the averages running 18, 16, 25, 20, 18, 25½, and 22 lbs. per ton, the average of all being 18.0 to 25.0 lbs. per ton, or 20½ lbs. as the general average of all. This corresponds to the accelerating force of gravity on a 1 per cent (52.8 ft. per mile) grade, and that being also the lowest grade, by universal railroad experience, upon which cars can be relied on to start off from a state of rest with little or no assistance, the correctness of this coefficient may be considered as well determined.*

* On a 0.7 per cent grade (14 lbs. per ton) the writer found it impossible in several instances for six men pushing, two with pinch-bars, to start two loaded box cars into motion. In no single instance out of over sixty did cars start without some assistance.

Normal Coefficient of Journal-friction at Ordinary Operating Velocities.—Certain general facts seem to be clear from all the various tests here considered:

The first of these is, that (1) the character and completeness of lubrication seems to be immensely more important than the kind of the oil, or even pressure and temperature, in affecting the coefficient.

This is very clear from the diagrams (Figs. 303 to 307) showing the various results. Mr. Tower found that lubrication by a bath (whether barely touching the axle or almost surrounding it) was from six to ten times more effective in reducing friction than lubrication by a pad. By this method of lubrication Mr. Tower succeeded in reducing the coefficient in a large number of tests to as low a point as .001, equivalent to only 0.2 lb. per ton of tractive resistance, and the general average in the bath tests, under all varieties of load and speed, is given as only .00139 or 0.278 lb. per ton, against 1.96 to 1.95 lbs. per ton with siphon-lubricator, or pad under journal. These results are very far below any heretofore reported, as will be seen from the following general average of results; not considering now the comparatively minor variations produced by ordinary working differences in temperature, load, etc.

The normal journal-friction, under favorable conditions, deduced from various series of tests, may be summarized as follows for velocities greater than 10 miles per hour, or 90 ft. per minute, journal speed:

Beauchamp Tower, bath of oil	.278	lbs. per ton.
" " pad or siphon	1.9	" " "
Thurston, light loads	2.75	" " "
" heavy loads	1.75	" " "
Wellington (gravity tests of cars in service), light loads	6.0	" " "
heavy "	3.9	" " "
" direct tests (as shown in Fig. 2)	5.1	" " "
	3.7	" " "
Thurston, inferior oils (Fr. and Lub., p. 173)	4.8	" " "
	3.0	" " "
Morin, continuous lubrication	6.0 to 10.8	" " "

These discrepancies, especially as they are accompanied by many minor ones, are very instructive, as showing that the character of lubrication is the great cause of variation of coefficient.

Resistance of Freight Trains in Starting.—It will be seen in Fig. 303 that the abnormally high coefficient of friction at starting continues during the period of getting up speed, and thus constitutes an extra tax upon tractive power for some little distance after getting under way.

The following conclusions may, it is believed, be drawn (already summarized in par. 635).

Effect of Temperature on Coefficient of Friction.—So far as can be estimated, the results agree very closely with Prof. Thurston's formula that the coefficient increases as the square of the increase of heat over 90° to 100° F. at speeds under 12 miles per hour.

Effect of Load per Square Inch of Bearing on Coefficient of Friction.—Comparison of the results obtained by the writer, and by Messrs. Thurston and Tower and others, as shown in Figs. 303 to 307, develop this curious fact: that while the results differ quite widely, in fact by several hundred per cent, in what may be called the typical or average coefficient of friction, they all agree quite closely in finding that the effect of increased load, within working limits, is to very materially diminish the coefficient. Mr. Tower, in fact, goes so far as to state, as one of the results of his tests, that it almost seemed at times as if it was approximately true that the *absolute* loss by friction was entirely independent of load, the coefficient falling almost to half when the load was doubled. But it seems plain, from the diagrams given herewith, that this result is only true on account of the unprecedentedly low coefficients which he obtained by his very perfect lubrication. Inspection of the diagrams will show that the general law of variation from increase of load is not materially different in the different tests, despite the wide variations in the average coefficients.

Effect of Velocity over Twelve Miles per Hour.—Figs. 303 to 307, taken in connection, seem to show the following:

1. The velocity of lowest journal-friction is 10 to 15 miles per hour,

2. With bath or other very perfect lubrication there is a very slight increase of journal-friction accompanying velocities up to 55 miles per hour (Figs. 306 and 307).

3. With less perfect lubrication, as with pad or siphon, greater velocity is as apt to decrease as to increase the coefficient (Figs. 304, 305, and 307). The latter being more like the ordinary lubrication in railroad service, we may say, without sensible error, that the coefficient of journal-friction is approximately constant for velocities of 15 to 50 miles per hour.

This has been the assumption which all investigators of railroad friction, to date, have been compelled to make, and it is, in some respects, fortunate that it proves not far from true.

Higley Roller-Journal Bearings.—The direct tests of this apparatus confirmed exactly the correctness of the writer's previously stated con-

clusions, that the Higley bearing was nearly as efficient as theory would indicate in reducing initial friction, but loses nearly all of this advantage under speed.

[The paper was followed by a long discussion, which it is necessary to omit, bringing out many further points of interest.]

APPENDIX C.

THE AMERICAN LINE FROM VERA CRUZ TO THE CITY OF MEXICO, *VIA* JALAPA, WITH NOTES ON THE BEST METHODS OF SURMOUNTING HIGH ELEVATIONS BY RAIL.

[Read by the author at the Annual Convention of the American Society of Civil Engineers, July 3, 1886. See Trans. Am. Soc. C. E., Nov. 1886.]

THE line described in this paper, and illustrated in the accompanying maps and profiles, is one located by the writer, as consulting and afterward chief engineer, from the Port of Vera Cruz to the city of Mexico, *via* the city of Jalapa, being a parallel line to the existing Mexican Railway—the first railway built in Mexico—in the sense of connecting the same termini, although following a very different route and of a very different character.

All the features of interest and of difficulty, both in the line here described and in the line of the Mexican Railway, are confined to the mountain grade by which the necessary abrupt ascent from the level of the sea to the level of the plateau, 8000 feet above the sea, is accomplished. Once on the plateau there is no great difficulty in going almost anywhere with very light work; many high mountains being scattered around, even on the plateau, but disconnected, with flat lands between.

The elements which appear to make the mountain grade of this line particularly worthy of description are these:

First. It is believed to be by far the longest continuous grade-line ever located; 116.9 kilometres (72.64 miles) having been located on an unbroken 2 per cent grade (105.6 feet per mile), rising in that distance from elevation 600.4 feet (183 metres) to elevation 7923.3 feet above the sea (2415 metres). The accompanying plate (Fig. 232) shows graphically the extent of the contrast in this respect with some of the other great inclines of the world.

Secondly. It is believed to be on the lowest rate of grade, by about 2 per cent, ever successfully attempted for accomplishing within a limited distance, either by a continuous grade-line or otherwise, a rise

of over one half as much as was attained on this line. The grounds for this belief also are shown in the accompanying plate (Fig. 232).

Thirdly. The line is believed to be, by probably one half at least, the cheapest line per mile which has ever been actually located, with equally favorable alignment, for attaining within a limited distance as much as one half the rise actually attained by this line, either by continuous or broken grade-lines, on any rate of grade. As for this, Table 190, Figs. 309 and 310, and the general knowledge of engineers are the only evidence that can conveniently be appealed to, or which it is worth while to attempt to present.

Finally. It appeared that the manner in which the line was obtained might have a certain instruction and encouragement to those who may be dismayed, as was the writer, by having similar problems of unusual difficulty suddenly thrust upon them, and it was also desired to give, in connection with the description of the line, certain conclusions which the observation and experience of the writer has indicated—not only on this incline, but on eight or ten others of considerable rise, which have been located or relocated in part or whole under his supervision, aggregating over 24,000 vertical feet—in regard to the most advantageous and economical manner of dealing with great inclines, under which may be classed anything exceeding 1200 to 1500 feet of vertical rise.

It is one of the unfortunate features of the department of engineering to which this paper refers—that of laying out railway lines to the best economic advantage—that a mere description of a located line has usually little technical interest or instruction, since it is ordinarily impossible to so carefully describe any line on paper as to enable even an intelligent impression to be formed as to the real character of the work. If the grades and work be light, it may be because the line was well laid out, or it may be simply because there were no serious natural obstacles in the way. On the other hand, if the grades and work be heavy, it may be due to bad engineering, and so discreditable; or it may be due to the existence of gigantic difficulties, and so an evidence of skill. It is but natural, however, that the magnitude of the natural difficulties to be overcome should in general be regarded as bearing some nearly constant ratio to the magnitude of the works constructed to overcome them; and hence, that, even when the construction of a very costly line may have been, as a matter of fact, an avoidable extravagance, due to lack of skill or foresight, the very magnitude of the works gives more instead of less reputation to the line as an engineering work.

Only in the comparatively rare cases when two independent alternate

lines exist between the same termini, is it possible for the engineer to find in printed descriptions of located lines, however perfectly mapped, any rational basis for intelligent judgment. The present happens to be one of the cases in which this is possible, owing to the existence of the parallel line before mentioned, but in order to avail of it, it becomes necessary to enter somewhat into what would otherwise be an invidious —because unnecessary—comparison with the parallel and previously constructed line. The writer feels the less embarrassed in doing this, as, owing to the checkered history of the line, no one engineer can be held responsible for its character, and there were certain circumstances tending to impede entire freedom of choice and proper investigation.

The whole interior of Mexico is a vast plateau, at an elevation of 5000 to 9000 feet above the sea, bounded by an abrupt escarpment from which the descent to sea-level is almost immediate. The edge of the plateau is higher and sharper on the Atlantic than on the Pacific Coast, and at no point on either the Atlantic or Gulf Coast is it higher or sharper than directly in line between the capital of the country, Mexico, and its chief port, Vera Cruz. Here two stupendous natural obstacles, the Pico of Orizaba on the south (17,873 feet high), and the Cofre, or "Box," of Perote (12,500 feet high), both of them described in physical geographies as volcanoes, although both are temporarily extinct, and the two connected by a ridge over 10,000 feet high at its lowest saddle—combine to forbid a direct line inward.

Orizaba is one of the three mountains in Mexico covered with perpetual snow, the other two being Popocatepetl (17,884 feet), and Ixtaccihuatl (15,705 feet), overlooking the valley of Mexico. These, however, start from a plain 8000 feet high, whereas Orizaba starts practically from sea-level on the coast side, making it in that sense by much the highest mountain on the North American Continent,* and among the highest in the world. Its snow-clad peak is visible 60 miles out at sea, long before there is any other evidence of land, and with the morning sun shining on it is a very striking sight. Its last violent eruption was in 1546, soon after the Spanish conquest, although it now occasionally throws out smoke. Only one or two men have ever ascended to its crater, the first one having been Lieutenant Reynolds, U.S.A., in 1848. The line of the Mexican Railway passes to the south of this mountain, as shown in Fig. 308.

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* Mount St. Elias, in Alaska, in a possible exception, being only about 30 miles inland, and its height variously given as 14,970, 16,900, 17,850, "over 18,000" (U. S. Census Report), and 19,500.

The Cofre, or "Box," of Perote (so named from a cylindrical basaltic needle about 300 feet in diameter and 300 feet high which caps the mountain, like a box laid on its peak), although formerly one of the most active volcanoes in the world, and classed as still active, is perhaps permanently extinct, its last, and probably also its greatest, eruption having been to form what looks to be, and is in fact, a frozen river of lava, shown in Fig. 309, extending to and running into the sea 50 miles distant, filling up an enormous barranca or deep gulch in the process, in a manner which was very convenient for subsequently carrying the line over it, as may be seen in Fig. 309. The natural variations in the width of this gulch have caused lakes and frozen "water-falls" of lava, which makes it difficult to believe, as one looks up the slope upon it from some commanding point, that the mass is not still flowing, making it a unique and impressive bit of natural scenery. Vessels have been frequently wrecked in the toe of this flow where it enters the sea. It has still hardly any deposit of sand, soil, or vegetation on it, that and other facts evidencing that the flow is geologically very recent, not antedating much the historic era.

Around the north side of this mountain, and directly over this lava flow, the line here described passes, as shown in Figs. 308 and 309, being about sixty miles north of the Mexican Railway line at its greatest divergence, the two beginning to come together again very soon thereafter. The summit of Perote is just below the limit of vegetation and of perpetual snow, and it is very easily ascended on horseback to the foot of the "cofre," or box, that fact alone being an evidence to the engineer of how different the topography of its slopes must be from those of its southerly companion. Evidences abound of tremendous flows of lava in remote geologic times, which are now covered to a considerable depth with soil, and in the kind of pocket formed between the foot-hills of the two great mountains, in which lie Jalapa and Coatepec, the detritus of ages has accumulated, including probably great amounts of volcanic ash, so that no rock exists over large areas, as was afterwards discovered, except in isolated points.

Cortez followed this route on his first invasion, as did General Scott 328 years later; but from an early date after the conquest of Cortez two leading routes have existed between the interior and Vera Cruz, following substantially the two railway lines here described, one through Jalapa, rounding Perote to the north, and the other *via* Orizaba, rounding the mountain of that name to the south. The northerly line was first constructed, and over it, for 300 years (between 1521 and 1812–20) passed

Region between Vera Cruz and the City o
co, showing the Line of the Mexican Rail-
and the Jalapa Line as originally sketched,
n substance afterwards located, below Pe-

vast sums of silver and gold, practically the entire product of the Mexican mines, amounting in the aggregate to $3,000,000,000, or nearly half of the value of silver in the whole world, which in 1876 was estimated at $7,232,071,674, exclusive of what existed before 1520, which was relatively little. During all this time the southerly route was an insignificant trail, but early in this century the southerly route took prominence, and the Jalapa *camino real*, or "King's highway" (as the leading roads are still called in republican Mexico), was suffered to fall into decay. It had originally been paved, guttered, and curbed for the entire distance from Jalapa to Vera Cruz, some 73 miles, and from Jalapa up the mountain a fine macadamized road, likewise curbed and guttered, existed, and still exists in fine order, having been recently repaired.*

Within fifteen or twenty years after the abandonment of the northerly highway, as early as 1837, the movement for a railway between Vera Cruz and Mexico was begun by Don Francisco Arrillaga, and very naturally, but very unfortunately, the route which had by that time become the only one generally known, assumed a prominence which it held to the end. The very facts which made it best suited for a highway, that a very comfortable valley ran directly up into the bowels of the mountains, from which the ascent was abrupt and sharp to the plains above, made it unsuited for a railway line, but this could hardly be appreciated at that early day.

By 1854 the construction of a tramway from Vera Cruz had been begun, Don Antonio Escandon, a wealthy Mexican banker, who was chiefly instrumental in pushing the project through to completion, having then taken hold of the enterprise. Don Antonio had a large estate near Orizaba, and his property interests may well have somewhat influenced the final decison. However this may be, in 1857, Colonel Andrew H. Talcott, an American engineer, arrived with a staff of assistants, the only member of which now living, the writer believes, is Mr. S. Wimmer, M. Am. Soc. C. E., then a very young man, after whom one of the leading bridges of the line was subsequently named. According to one of the published histories of the road, all these engineers confined their labors to the Orizaba line, that *via* Jalapa being intrusted to a Mexican engi-

* On the lower part of this highway a splendid stone bridge, the *Puente Real*, or as now described, the *Puente Nacional*, which has been not unreasonably claimed to be "worthy of the best days of Rome," still exists in perfect order, and as showing the fine quality of the Mexican lime, the joints are considerably harder than the stone itself (which is durable but rather soft), and are worn less.

neer, Don Pascual Almazon. According to other accounts, a commission of engineers examined both lines. If the first was the case, it is less surprising that "on comparing the separate surveys," as the history of the road states, that by Orizaba was finally adopted, on the grounds, first, that there was more traffic to be secured on it (which is rather more than doubtful, although the local traffic at best is an insignificant element), and secondly, that "notwithstanding it requires great and costly works, the line presents greater facilities than that by Jalapa, *where the larger number of ravines and the harder nature of the soil would have required much heavier outlay.*" A greater mistake than is contained in the italicized part of the quotation could not well be.

Colonel Talcott's estimate of the line was $15,000,000, but nothing more was done than to build about ten miles of surface line out of Vera Cruz, until August, 1864, when the military necessities of the Emperor Maximilian led to a real beginning and prompt pushing of the work under English engineers, and by an English company, which still controls it. Beyond a statement that the resumption was "after rectifying the plans of Colonel Talcott," the official history contains no record of the second examination of the whole question of route, which was in fact made, although how thoroughly the writer cannot state.

By 1867 the line was opened from Vera Cruz to Paso del Macho, 47½ miles, and from Mexico to Apizaco, 86½ miles, the rails for the latter being hauled by wagons an average of 200 miles inland, at enormous cost—a hard condition imposed by the Mexican Government. A third change of engineers took place about this time, while the heavier parts of the work were still unexecuted. In 1868, the Puebla branch, 29 miles, was opened, the rails for it having been hauled in the same manner. In 1870 the line was opened to Atoyac, 54 miles from Vera Cruz; in 1871 to Fortin; in 1872 to Orizaba, and on the last day of that year the entire line was opened with great ceremony.

Shortly thereafter, in 1874, Don Ramon Zangronez, of Vera Cruz, succeeded in getting a branch line to Jalapa well under way, and in having it assumed by the Mexican Railway, which completed it, as shown in Fig. 308, in May, 1875. It is operated solely by animal power, being probably by far the longest horse railway in the world. Its grades are very severe (10 per cent), and its curves of ordinary horse-car radii. It is laid for a great part of its length along the old *camino real,* and exhibits the same trait as the main line of the Mexican Railway to the foot of the mountains—that is, it runs obliquely across the drainage lines, thus materially increasing the difficulties of both lines, but making

the Jalapa line absolutely impracticable for an ordinary railway, even with gigantic work. It was probably some such erroneous treatment of the lower part of the descent which led to the condemnation of the route, as it seems impossible that an ascent from Jalapa on a 4 per cent grade could have been deemed as serious as that from Orizaba on the adopted line.

The main line thus constructed is still one of the most massive and costly in the world. Its cost was abnormally increased by two causes: First, the political condition of the country, which was so much disturbed that it no doubt added much to the cost; and secondly, the absurd requirement that construction, including track-laying, should begin from both ends at once, necessitating the enormous expense referred to for hauling rails over execrable roads from Vera Cruz to Mexico and Puebla. In all some 15,000 tons of rails were thus hauled, at a cost, the writer believes, of some $80 per ton, amounting to some $1,200,000 in all. On the other hand, there was little direct inflation of the capital account, most of the share capital representing actual money paid in. The gross nominal cost of the line was, as nearly as may be, $40,000,000. Reducing this by one half, we shall make an ample allowance for the effect of all abnormal causes tending to increase cost of line, and for the cost of the Jalapa horse railway and the small amount of rolling-stock (65 engines, 810 cars), leaving $20,000,000 to represent the actual cost of 264 miles of main line and 29 miles of branch. Of this the section between Paso del Macho and Boca del Monte alone, some 60 miles, is in any sense difficult or costly work. The remaining 223 miles is light work, with 1½ per cent grades, which latter are quite unnecessarily high.

On this basis we may distribute the actual cost (taken at half the nominal) about as follows:

223 miles light work, at $40,000 per mile	$8,920,000
60 miles very heavy work, at $184,667 per mile	11,080,000
283 miles in all, at $70,670 per mile	$20,000,000

Both the grades and curves on this line are very severe. Only 10 miles out of Vera Cruz 1.5 per cent grades begin, which shortly thereafter are increased to 2 per cent, 2.5, 3, and at last to 4 per cent, which latter is entirely unbroken for the last 13 miles of rise, and used also at several other points on the ascent. Curves as sharp as 325 to 350 feet radius (16 degrees 30 minutes and 17 degrees 40 minutes) are used, and six or eight reversed curves of these radii often succeeding each other without any tangent between them, and without any grade compensation, making

the virtual gradient fully 6 per cent. Fairlie engines are used to operate this grade between the summit at Boca del Monte (107 miles from Vera Cruz) and Cordova. The remaining 157 miles to the city of Mexico, as well as the lower and easier part of the mountain grade (which, however, has 2½ to 3 per cent grades, increased by unreduced curvature), is operated by American engines. Very naturally both the freight rates and the expenses are fabulously high, receipts ranging from 10 to 12 cents per ton-mile and as high as $8 per train-mile, expenses being from 50 to 60 per cent of receipts. To show how radically the cost and revenue from the operation of this line differs from anything with which we are familiar, it was calculated in 1883 that with the Mexican rates the New York Central would earn $27.25 and the Erie $28.50 per freight train-mile, and their total freight earnings would have been in one year $297,025,000 and $244,300,000 respectively—$168,000,000 more than the Central's whole capital account, and $93,000,000 more than the Erie's.

There are fourteen tunnels in all on the line, none of them, however, very long, and about as many viaducts. The grading is, for miles together, almost wholly rock, and the work, as a whole, can only be described as Titanic, so that it is small matter of surprise that almost every one who writes about the line describes it in much the same terms as does Mr. George William Curtis in a late number of *Harper's Magazine* (February, 1886), who chances to be the last writer whose remarks in respect to it have come to the writer's knowledge.

"If it is magnificent scenery that you seek, here at hand, with no intervening ocean, is the railway from Vera Cruz, 260 miles, to the city of Mexico —a marvellous feat of scientific skill, crossing the mountains at a height of 8500 ft., and bearing you through every climate, amid unimaginable luxuriance and brilliancy of vegetation, changing into temperate hues of hardier growths, with awful mountain abysses between and snow-clad peaks beyond against the deep blue sky."

The line located by the writer rises to almost precisely the same height of summit as the Mexican Railway, and is as nearly as may be of the same length, but in almost every other detail stands in broad contrast with it, thus:

GRADE.—Continuous 2 per cent (uncompensated) against a broken 4 per cent (uncompensated); including the effect of curvature or of compensation therefor, 2.6 per cent against 6 per cent.

CURVES.—Curves of 289 ft. radius (19° 50′) connected by minimum tangents of 40 metres (131 ft.), against 16° 30′ to 17° 40′ curves (325 to 350 ft. radius) connected by no tangents at all for many successive reversions. The writer con-

siders that the difficulty and expense of maintaining these two limits is about equal, but that the latter is decidedly the most objectionable.

AMOUNT OF CURVATURE.—On Mexican Railway 143 curves on the last 20 14 kilometres of the ascent, against 82 curves on the upper 19 kilometres of the Jalapa line, shown on Figs. 309 and 310. The lower portions of the line will be seen in Fig. 309 to have much more favorable alignment.

The number of curves indicates, what is the fact, that there is hardly any tangent on the upper portion of the Mexican Railway grade, whereas on the upper third of the line, shown on Figs. 309 and 310, 41½ per cent of the line is tangent (the average tangent being 96.3 metres or 320 ft.), and on the whole 54 kilometres which have been engraved 48 per cent of the line is tangent. The comparative degrees of curvature cannot be given.

DISTANCE.—The distance between Vera Cruz and San Marcos, where the two lines as actually surveyed connect, was just 20 kilometres (12½ miles) longer *via* the Jalapa line, viz., 262 against 242 kilometres. Had the purpose in view been the same, however, merely to get to Mexico, this difference might have been more than eliminated, as will be clear from the dotted line above San Marcos on Fig. 308.

GAUGE.—The Jalapa line was intended to be laid to 3-ft. gauge, corresponding to the gauge of the Mexican National Railway, whereas the Mexican Railway was 4-ft. 8½-in. gauge. No difference was made in the location, however, on account of the gauge, the road-beds having been taken as 14 and 18 ft., slopes 1 to 1 in cuts and 1½ to 1 in fills, and rails estimated at 56 lbs. The ties were estimated at $1 each, only 7 ft. long, which was the only item estimated in any way lower because of the gauge.

COST.—In Table No. 1 (omitted) is given an abstract of the large estimate blank prepared from the careful paper location of the entire mountain grade. Table No. 2 is an abstract closing a report by the topographer, giving in detail the material on the line, from which, in connection with Fig. 310, its very favorable character will be seen. From these and the maps and profiles submitted, which even in the reduced engravings show the estimated quantities at each point, any engineer can form his own judgment as to whether the estimate in Table No. 1 (omitted to save space) is adequate. The writer's belief was, and still is, that it is entirely adequate, and if so the cost of the entire mountain grade, with 30 per cent added for engineering and contingencies, amounts to less than $40 000 per mile, against $184,677 per mile for the actual cost of the mountain-grade of the Mexican Railway, or in the ratio of 1 to 4½. A ratio of 3 to 1 is believed to be the very lowest which could be claimed to correctly represent the relative work. Unfortunately the writer was never able to obtain exact figures of the quantities on the Mexican Railway. Therefore he is reluctant to claim more than is certainly just.*

* The general route of both lines here described is shown in Fig. 308. In

Make what allowances one will, there is a great contrast in these two lines, and it therefore becomes of interest to consider how this latter line was obtained.

In March, 1881, the writer was engaged by the Mexican National Railway Company to act as engineer in charge of location and surveys on the various lines for which they had concessions, extending from the city of Mexico to the United States and to the Pacific coast. On landing at Vera Cruz, with a large staff, under orders to report in Mexico, he was surprised at the receipt of a letter of instruction to the effect that a corps were engaged in examining a line from Vera Cruz to Mexico *via* Jalapa, and that he should detach another corps for service on this line, sending forward the remaining parties by rail; that he should then make a reconnaissance "sufficient to determine the general possibilities of the route, taking such escort as might seem necessary;" set the new and old parties at work; and not delay date of report in Mexico "more than six days."

Fig. 309 is given a reduction to one-fifth scale, or $\frac{1}{50000}$ ($1\frac{1}{4}$ inches per mile, within 1 per cent), of the large topographical map on a scale of $\frac{1}{10000}$ of the upper 54 of the 117 kilometres of the mountain grade. This in turn was reduced from the original field-sheets on the large scale of $\frac{1}{1000}$ or $83\frac{1}{3}$ feet per inch, which the difficult character of the work made necessary. The topography was very accurately taken by a skilled topographer, Mr. Max Chapman, M. Am. Inst. M. E.

In Fig. 310 is given a photographic reduction of the original profile, which was called off, station by station, in the usual way from a paper location on the original field-sheets, and estimated, station by station, from tables, with allowance for surface slope, which often more than doubled the level-section quantities. The estimated quantities for each cut and fill are given on the profile and nature of material indicated. Retaining-walls were estimated for at every point where a fill would not catch, and are indicated by a thick line on the profile. The small amount of masonry is due to the almost entire absence of surface drainage and running water, as elsewhere noted.

The line, profile, and estimate here shown were not finalities, but prepared for a special purpose. Compensation for curvature had not yet been introduced. It was fully expected to do still better at points, and in fact the location shown was greatly improved in the upper section (9) by a new line, run just before the suspension of work which threw the line back from the ragged cliff-work near the summit. As maps and profiles of this improvement cannot be given, no claim in respect to it is made, but only for what had been actually secured and recorded in black and white.

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To one landing in Mexico entirely ignorant of the language and the country; provided with no map or profile of the existing line, and knowing nothing more of its character than the general fact that it was one of the heaviest and most costly railways in the world; unaware that its engineers had even given a thought to a route *via* Jalapa, or even that there was such a place, until he finally learned that the route had been examined only to be abandoned, and that the branch which had been built to Jalapa, at the foot of the mountain proper, had 10 per cent grades, and was practicable only by horse-power; unaccustomed to a tropical climate and to the saddle; provided with no map of the region better or much larger than Fig. 308 which accompanies this paper; and innocent of all knowledge as to how large an escort would insure safety, if indeed any could—these were sufficiently formidable instructions, and could never have been successfully carried out, as fortunately they were to the letter (barring two days' delay from an unseasonable rain), had reconnoitring such lines been in fact so entirely lawless a matter that there was nothing for it but to look over the whole country and then decide what to do, or at least to try for.

The line which was found to be under examination is indicated by dotted lines on the general map herewith, and was at once rejected as impracticable and absurd. It ran from the coast north-easterly to Jalapa, 4500 ft.; then descended southerly, 850 ft. in about 10 miles, to an elevation of about 3650 ft. at Coatepec; then was expected to ascend somehow, some 7000 ft. to the "pass" between the volcanoes of Orizaba and Perote, at an unknown elevation, estimated at 10,700 ft. in an air-line distance of some 15 miles; and then to descend some 2000 or 3000 ft. on the back slope of the mountain, to the general level of the plateau. Very naturally the best grades which it was even hoped to obtain were those of the Mexican Railway, or 4 per cent uncompensated.

It was at once clear that either something considerably better than this must be obtained, or the line should be reported as impracticable and the whole staff withdrawn. And it seemed equally clear to the writer that either a considerably better gradient than on the existing line must be obtained, and lighter work as well, or the project reported as undeserving of any consideration financially. A reasonable hope for a maximum grade of not over $2\frac{1}{2}$ per cent at most was therefore fixed upon as the highest one justifying setting parties at work on it, and hence to be considered at all; and this, to make the project a meritorious one, required that 2 per cent should be sought for. This made it indispensable to gain considerable development for the ascent, and this in turn made it out

at once that there was, and a very old and good one. Had the response been otherwise, he should have regarded the result of the reconnaissance as practically decided then and there. The statement was coupled with another, however, that this route had been examined by the engineers of the Mexican Railway, and reported far less practicable than the line afterwards adopted and built, so that the middle line described was under examination as the only hope left.

This was discouraging enough; but on further learning that the highway had been for three centuries preceding the railway era the leading one between the interior and the coast; that there was no succeeding descent, but rather a gentle rise in it for many miles after the mountain-grade proper was surmounted; that the summit was (this afterwards proved an error) several hundred feet lower than that of the Mexican Railway; and some other facts which seemed hopeful,—there appeared to be a fighting chance, which was at least the only chance that the line might be developed to give the requisite grade.

The more immediate question became then to make the ascent of 4500 ft. to Jalapa, and it was at once apparent that to have any hope of doing this on such favorable grades as were alone worthy of consideration under the circumstances, the line must be carried down to as low an elevation as possible, parallel with the coast and the mountain slope, by running south from Jalapa toward Coatepec before beginning to lose distance by turning eastward to the sea. It appeared probable that the 850 ft. of fall between these two points, as to which some definite knowledge was available, could not be made on a steeper grade than 2 per cent, and it was this fortunate fact (as it proved) which first led to conducting the reconnaissance from the beginning on the fighting chance of obtaining a 2 per cent grade.

It was now determined, therefore, that the line, if there was to be any, must pass from Vera Cruz to Coatepec, and thence to Jalapa, instead of to Jalapa direct. Coatepec lies at the head of a river of considerable size, the Rio Antigua, which runs from it directly east to the coast; and the map and known elevation of the town made it at once clear that there was no physical impossibility in descending this valley directly on a 2½ per cent grade, or perhaps less, if the valley had a tolerably uniform descent. It needed but the most moderate knowledge of the general laws of topography, however, to make it practically certain that no even approximately uniform descent could be hoped for in a river flowing in a deep gorge, cut through what was practically only a narrow footing to the most tremendous mountain slope on this continent. The foot-hills

of a slope which reached a height of 17,873 ft. and started practically from the level of the sea, was certain to have, like all such slopes, a decidedly concave profile.

Nothing less than 5 per cent could be rationally hoped for in following the bed or immediate slopes of the valley, and it therefore became quite certain that the line descending from Coatepec must start from the lowest point at the head-waters of the Rio Antigua which it was possible to obtain, but speedily rise up on the higher slopes of the valley and out of the influence of the stream, until at last—and probably within a short distance—it would rise above all supporting ground. No resource would then remain but to turn across northwardly, at some favorable point on the dividing ridge, into the valley of the next river to the north, the Rio Chachalacas, with the view of gaining only such limited development as might be necessary to catch upon some high point on what were known to be the gentle slopes of the lower valley of that river, from which the line could descend eastwardly on the required grade to sea-level at a point as near to the coast as possible. The only fear in this process, besides the danger of heavy work, was that it might be unavoidable to make a long horseshoe development up the valley of the Chachalacas, bringing the foot of the grade far inland from the sea, and causing just so much unnecessary loss of distance on a level before reaching the foot of the mountain grade. The existence of these two parallel and deep-lying streams made it certain that the general scheme below Coatepec would be practicable, if not too costly; and the immense depth of the southerly valley, which varied from 1000 to 2000 ft., together with the absence of all supporting ground to the south of it, made it certain that the line could at no point turn south between Coatepec and the coast.

Thus, by a process of exclusion, the entire line was projected and sketched upon the map, with most dismal apprehensions of the character of the work which would be encountered, but with absolute confidence, expressed at the time to the gentlemen who accompanied the writer on reconnaissance, in the face of some opposition, that if this line was not practicable, there was nothing in the region which was sufficiently defensible, from an economic point of view, to make it even worth examination. The line shown on the general map (Fig. 308) which the writer now has the honor to lay before the Society, does not differ by its own width at any point in the entire ascent of nearly 8000 feet to the plateau from that which the writer thus sketched upon the map in the city of Vera Cruz, and showed to several gentlemen, on the evening of the day when he first landed in Mexico, within two hours after first

learning that there was such a place as Jalapa, or that there was, or ever had been, such a project as an ascent to the plateau through that region, and with the elevation of only two points on the line, Jalapa and Coatepec, approximately given. Neither does the line on Fig. 308 differ by much more than its own width at any point from the position of the line as finally surveyed, as shown on the detailed maps and profiles which are herewith laid before the Society complete, the more difficult upper half of the mountain grade only having been engraved on Figs. 309 and 310.

The writer would not be understood to assert or imply that equal positiveness in defining in advance the limitations of reconnaissance is often possible. On the contrary, he has never known another instance just like it, although it became his duty later to consider projects for several other lines of a similar but less exacting character. But the peculiar conditions, it will be seen, left no escape at any point from the chain of reasoning. Had there been no existing parallel line, one might have justifiably taken the region for better for worse, and borne with equanimity finding it a great deal worse than he took it for. As it was, the fighting chance for a low grade was the only one economically worthy of attention, and this primary fact given, the conditions left no escape at any point from the train of reasoning that it was that one route or nothing.

The next morning at daybreak the reconnaissance began, and was pushed through with increasing confidence as fast as the animals could stand it, or at the rate of some 40 miles per day, the entire examination of the mountain grade occupying three days—such haste being merely in fulfilment of the writer's positive instructions, and naturally against his inclination. Less time was required, however, because the only real purpose of the reconnaissance was not to find a route, but to examine on the ground the features of what was already known to be the only route affording a rational chance of success. The first 1500 feet of rise was seen to be on slopes smooth in detail, but sufficiently steep for laying down a surface line on almost any grade, and were not examined critically. The dividing ridge was then followed up, to judge of what was really the only critical point of the lower descent (from the point of view of possibility and not of cost), the passage from one water-shed to the other. A long and sharp spur ridge running eastwardly from Coatepec about half way to the coast, having a crest 5000 or 6000 feet high, and standing at right angles to the main slope, was found to define the point where this passage must occur pretty definitely, and the material and topography was seen, with much relief, to

be favorable for making this passage with as much or as little development as might be necessary, with considerable latitude in elevation and easy work. The south slope of this mountain, where the line would lie, was found to be almost impracticable for passage on horseback without camp equipage and time; but observing the north side to be fairly favorable, and taking it to be very unlikely that, in a ridge of this character, the topography would differ widely on the two slopes, it was passed by with a confidence that the result fully justified, as well as such very limited information as was available at the time. It will be seen from the maps and profiles of this section (not engraved) that on the surveys now submitted, a few of the most costly single works on the line are here, and not on the engraved section above Jalapa, which was really the critical section. This, however, the writer is, and was then, satisfied was due chiefly to the fact that the lower section, not being a source of much anxiety, was left in less competent hands. In part it was radically improved almost at the conclusion of surveys, and the writer feels no doubt that it all might have been more or less, although he makes no claim in that respect. Owing to the falling away of the country to the south, before referred to, and the existence of the deep *barranca*, or gorge, in which the river lay, which cut down almost to sea-level, or some 3000 feet below the line, some of the most sublime views of the line were on this section; but its difficulty was not in proportion, in part because of the very fact that the line lay so high as to be above the immediate influence of the *barranca*. The material on all this section was exceedingly favorable.

The region between Coatepec and Jalapa was known to be not very rugged, and to oppose no difficulty as to elevation, so that it also was passed by with a confidence which the result justified, and the project was complete to Jalapa, as a basis for surveys, with a reasonably favorable 2 per cent grade-line all but assured.

For the critical section above, the distance by highway was found to be almost one half too short, and all hung upon the possibilities of development. The material and topography on the lower half was found to be favorable for this purpose, being earth to a great depth, as noted, and sufficiently broken up by ridges and hills. A long stretch at about the middle of the slope, near the village of San Marcos, was of an equally favorable character, being literally an inclined plane on a slope of about 1 in 10,—an old lava flow overlaid with soil,—and not much broken up in detail. The upper section was rugged, but short, with considerable opportunities for rather expensive development.

The whole of this region was examined on the third day of a very heavy rain-storm, the end of which could no longer be waited for, and the examination was necessarily restricted to salient features only. On a long grade-line of this character, however, the possibilities of developing on practicable ground to reach certain elevations at certain fractional portions of the available distance, can be judged of with some certainty, the general character of the slope being the main feature; and the writer felt no real doubt then, or at any later time, that a grade in the neighborhood of 2 to 2½ per cent was easily practicable, there being a certain considerable belt of favorable territory on which to place it, although above and below that the topography was much more forbidding. A leading factor in reaching this apparently hasty conclusion was the splendid and ancient highway already referred to, by far the best in Mexico, if not on this continent. It is a broad macadamized road with paved gutters, and a stone curb or masonry wall at the side, and the writer desires to pay a tribute of admiration and respect to the unknown engineer, whoever he was,—very possibly one of the soldiers of Cortez, or one of his immediate successors,—who laid it out. From a point near Jalapa to the summit, near Las Vegas, there is not a break in the steady ascent, and there are few points on it where a fresh team of horses would not readily break into a trot. The conclusion was natural, that if a Spanish soldier in 1530 could put something like a 6 per cent highway down that mountain slope, an American engineer in 1881 ought to get a 2 per cent railroad line down it, or take off his hat to his predecessor.

After reaching the summit, the continuation of the line to Mexico, or any other point on the plateau, was a detail offering no difficulties and needing no immediate study. The line was therefore reported on in writing to Mr. W. C. Wetherill, chief engineer, three days later (March 28), as follows:

"The line under examination was too forbidding to be worth further attention. . . . I feel no doubt that the proper place for the line is to the north of Perote, and that something like a 2½ per cent grade, or possibly a 2 per cent grade, is practicable above Jalapa. Whatever grade is there obtained can certainly be continued down to sea-level and slope without excessive work. I have instructed surveys to be conducted above and below Jalapa on a 2 per cent basis for the present, and consider the prospects for a fairly favorable line good."

It should be mentioned further, that the writer's examination had been merely in a consulting capacity (the line not being formally a part

of the Mexican National projects), and for some months later he had no permanent connection with or knowledge of the progress of the work, being absent on the Pacific slope. On being again asked to examine the line, August 1st, 1881, he found that his conclusions had been reported on as impracticable, and that a 3 per cent compensated grade had been adopted, located in part, and was under construction.* Fortunately, however, a most intelligent assistant engineer, of great natural capacity for location, Mr. JOHN S. ELLIOTT, was in charge of the upper locating party. To his admirable conduct of surveys the success of this line was very largely due. Aided by information he had acquired, it was soon discovered that the abandonment of the 2 per cent grade had been an over-hasty conclusion, from data which in fact assured its success. The work in progress was therefore stopped by the writer's advice; some $30,000 of completed work abandoned, chiefly in the approaches to a costly tunnel in earth; and the writer appointed chief engineer, continuing in charge until some time after the completion of the surveys now laid before the Society, when the abandonment of all furtherance of the project by the Mexican National Railway compelled his resignation, and shortly afterward led to the stoppage of all work. But for the fact that he was favored with an unusually competent assistant in immediate charge of surveys on the more difficult section, the writer fears that he should never have been able to carry through the line with the limited time at his command.

Two features on the upper ascent are worthy of special note: One, the great lava flow shown in Fig. 309. and before referred to; and the other, a still grander feature, the *barranca* of Zimilahuacan, a vast sink-hole in the earth some 2 or 3 miles in diameter, and some 3000 feet deep by the barometer, about half of it sheer, with no transition or "ragged edge" whatever from the surrounding surface of the plateau, which was as smooth and treeless as an Illinois rolling prairie, but sloping about 1 in 12 or 15 in the chasm. This feature was encountered some miles beyond, where all difficulties had ceased at the summit; and so smooth was the edge that the line skirted it with a mere surface line, so near to it that a stone thrown from the car-window would fall sheer full 1000 feet before touching. On the plateau the locality was so cold and so much exposed that it was stated that wheat would hardly head, while immediately beneath one's feet bananas, coffee, oranges, and every form of tropical vegetation could be seen growing luxuriantly. A few miles beyond was

* The concession permitted of no delay in beginning construction.

a large and very ancient fortress still in good repair, but unoccupied, which would cost perhaps $5,000,000 or $6,000,000 to duplicate, in which for two centuries the great bulk of the silver product of Mexico was stored pending the arrival of transports at Vera Cruz. Several of the old line of visual telegraph towers which were used to communicate between the two points are still pointed out, although out of use more than a century. From several points on the upper ascent the city of Vera Cruz, 80 miles off in an air-line and 6000 to 8000 feet below, is visible in clear weather. These and other features make the region one of the highest interest to the tourist.

In view of what has preceded, the writer hopes that he may not be suspected of over-estimating the difficulties of securing such lines, or of personal inability to cope with them, when he declares his conviction that this whole method of taking railway lines up difficult ascents by a continuous succession of curves and tangents on a rising grade, over which the locomotive keeps up a steady march, is fundamentally wrong and bad, and one which might profitably be modified in nearly all cases when an elevation of over 1000 feet, or possibly much less, is to be surmounted. To furnish a suitable background for the expression of these conclusions, by showing that they are formed in spite of fairly successful experience in following up the more usually approved plan, is a main purpose of this paper.

Three general methods for surmounting such elevations, besides the almost universal one, are more or less in use:

First. Rack or grip railways.

Second. Inclined planes operated by stationary engines.

Third. Switchbacks.

The first of these was proposed in a practicable form over thirty years ago, and the two latter antedate the locomotive itself. Either one of them is probably deserving of more use than is given it, but the third (switchback) the writer deems worthy of adoption by engineers as the standard plan for surmounting considerable elevations, always provided the switchbacks be constructed and operated in quite a different manner from that usual in the few which exist, which have for the most part only been resorted to as a last resource.

One feels a natural hesitation in expressing a conclusion which, it must be admitted at once, all the tendency of modern practice tends to discredit. The accumulated verdict of experience is rarely wrong, and it is undeniable that all these plans have been in many cases tried and abandoned, and have met decreasing favor. Nevertheless, causes need-

less to go into, other than lack of real merit, may explain in part at least this result, and the writer sees no escape from believing that they do so wholly.

The capabilities of the inclined plane or cable plan have been greatly extended in recent years, as applied to street and local passenger service, and it is clearly destined in the near future to still wider use. Superficially, the record of its use in connection with ordinary railways is most discouraging to any hope of its future usefulness in that direction. In the early days of railways it was constantly considered, and often used. A complete plant of the kind existed over the Allegheny summit of the Pennsylvania Railroad before that line was built, and was abandoned in favor of locomotive traction, even to connect two lines of canals. Several complete railways operated by successive inclined planes and gravity inclines were built in Pennsylvania and elsewhere—two in Northern Pennsylvania of considerable length, one of which is still in use and the other only recently abandoned, but not chiefly, if at all, for reasons affecting its abstract merit. It is not generally known that the existing main line of the Pennsylvania Railroad over the Alleghenies, which was built long after the old planes had been abandoned, was laid out with the distinct view of afterwards adding a new and enlarged system of planes for freight traffic when the volume of traffic had increased to justify it. This policy was favored by its distinguished chief engineer, Mr. J. Edgar Thompson, and some elaborate and interesting data in respect to it are given in the early reports of that road, notably in a report by the then Superintendent, Gen. Herman Haupt, in which the ground is distinctly taken that it is a mere question of volume of traffic whether inclined planes are economical or not.

That view the writer apprehends to be the true one. The fixed tractive plant is costly to construct, maintain, and operate, and expenses are not greatly affected by whether the tonnage moved by it be large or small. It by no means follows that, because the system was wisely abandoned in favor of locomotive power, for the thin traffic of those early days, that it is wise to continue to neglect it at points where almost a steady stream of laden cars is to be carried, first up and then down a dividing ridge, day and night, the year round, as on the Pennsylvania summit, and at many similar localities. At such points it is demonstrable that not only may the great amount of power used in lifting locomotives be saved, but that the descending and ascending cars may be balanced against each other, thus largely eliminating the effect of the rise; while the superior economy of stationary engines will largely reduce the

cost per horse-power, after allowing for the friction of cables, which, on a short, steep incline is a minor element. Especially now that the making of long continuous cables is so well understood, so that as long an incline as the topography permits may be readily worked, it is worthy of the most serious study whether a very large economy is not readily possible at such special localities, a considerable number of which may be counted up.

A proper switchback system, however, seems to the writer the most generally useful and meritorious for lines of probably thin traffic, as well as the most unquestionably practicable for use in all such localities. The germ of the proper system was contained in the first switchback laid out in America, if not in the world,—that at Mauch Chunk,—which was used for dropping empty coal-cars down into the Nesquehoning Valley, before the tunnel of that name was completed. That track was used only for cars passing in one direction (descending), and was operated as follows:

The cars were started from *A*, Fig. 311, on a down grade of about 1 per cent, calculated to give a considerable velocity. At *B* an automatic switch, whose exact mechanism the writer cannot give, was run through and the car brought to a rest by the next succeeding up grade at *C*, from which it immediately started back towards *D*, passing through the switches *B* and *D* until again stopped at *E*; and so on indefinitely, the cars descending several hundred feet in all without the slightest attention, very rapidly, with very rare accidents, and with no one on them or stationed along the track.

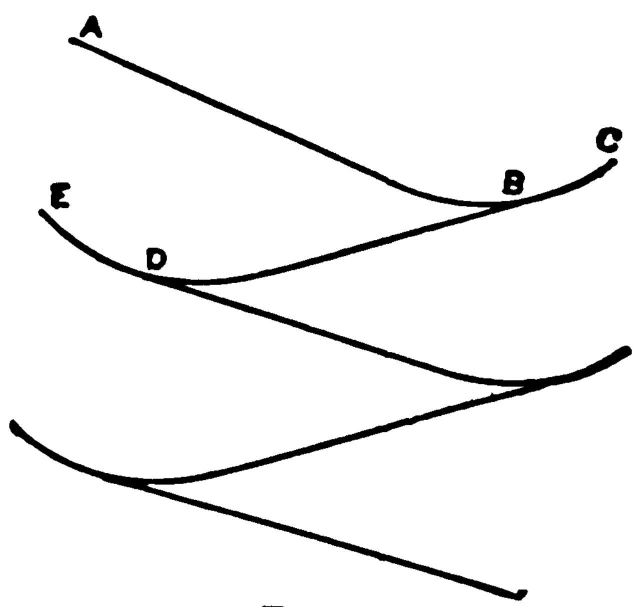

FIG. 311.

Thus, to say the least, every advantage was gained that could have been gained by a long continuous descent, with the immense advantage that, owing to the entire liberty of choice as to the length given to each plane, the best alignment and lightest work available on any part of the surrounding country may be chosen.

But more than this was gained. Any long continuous grade which is steep enough to move cars with journals in rather bad order, must be steep enough to speedily give cars in good order a dangerous velocity. Thus it would be impossible to let cars run of themselves down a continuous grade of any kind, while, on the switchback, not only was this

very readily done, but a pretty high average velocity could be safely used, from the fact that it in any case could not exceed a certain maximum. Again, when necessity required, it was easy to stop cars at any point.

Analogous advantages are readily obtainable, ***mutatis mutandis***, by switchbacks operated by regular trains running in both directions, but not under the conditions of ordinary practice, which necessitates the complete loss of all the *vis viva* of the train at every switch. The plan shown in Figs. 312 and 313 will apparently obviate this necessity completely, and introduce no new elements liable to cause difficulty, but, on the contrary, give smooth, easy, and rapid motion. The details of this plan are as follows:

As Respects the Switches.—The switches should be, and are easily made, entirely automatic. Their normal position should be that in Fig. 312, in position for running up hill, and not down hill. A runaway train or car cannot then pass a switch and continue down grade. As respects a train going up grade, this arrangement presents no difficulty. It may simply run through the switch *D*, springing the points over to let the wheels pass. Simple devices of many different forms may be used to restrain too rapid return of the points after the passage of each single wheel, but this is not essential, as the wear and tear would be small.

The mechanism here outlined acts as follows:

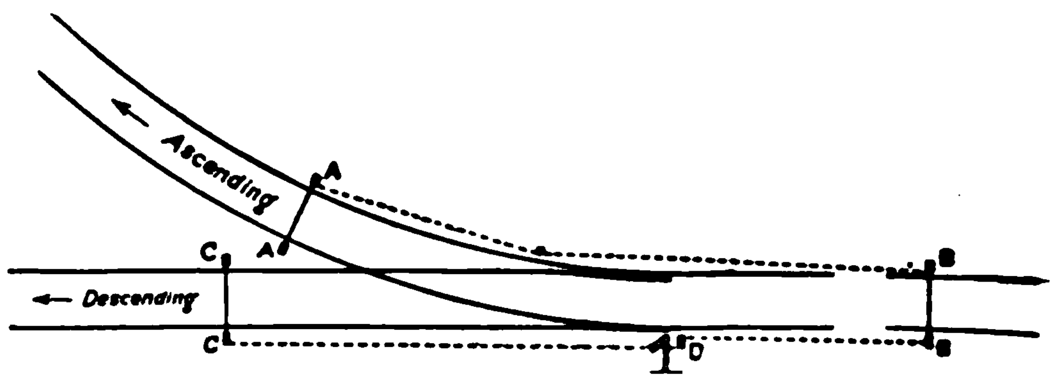

FIG. 312.—MECHANISM FOR AUTOMATICALLY OPERATING THE SWITCHES OF SWITCHBACKS.

DOWN TRAINS.—*A* places *B* and *C* in position to act, which are otherwise entirely inoperative.

B, when first made operative by *A*, opens the switch *D* for track *C*, and holds it open.

C, always operative when *B* is, returns *A*, *B*, and *D* to their original positions.

A, *B*, and *C* are supposed to be located with reference to having the engine always at the same end of the train. If the engine be at the other ends the switches must be operated by hand.

UP TRAINS.—If, by carelessness, the engineer of an up train should leave the switch-actuating lever down, nothing will happen except to set *A* as if for a down train, in leaving the switchback. This will not affect following trains, either down or up. Should a succeeding up train be equally careless, it will act first on *C* and then on *A*, thus running through the switch with no effect.

A train descending should be able to operate the switch, so as to continue descent, by a single act of the engineer, but only by intention on

his part. This may be accomplished by a very simple and inexpensive apparatus, such as that outlined in Fig. 312, operated by a lever or idler wheel on the locomotive controlled by the engineman, and with mechanism somewhat similar to that of the simpler forms of interlocking apparatus, which it would be superfluous to describe in detail, as it can be designed in a few hours by any signal engineer. The general method of operation is described beside Fig. 312, the whole insuring that (1) up trains shall always pass the switches freely and automatically; (2) that runaway down trains shall never pass them, but be caught; (3) that regular down trains shall be enabled to pass the switches automatically by a single act of the engineer; (4) that careless neglect of this act shall do no other harm than to cause the train to run back again on the up track; (5) that danger signals shall be set when the switches are wrong, or any part of the apparatus broken; (6) that the switches can at all times be operated by hand if desired, or if the mechanism is out of order.

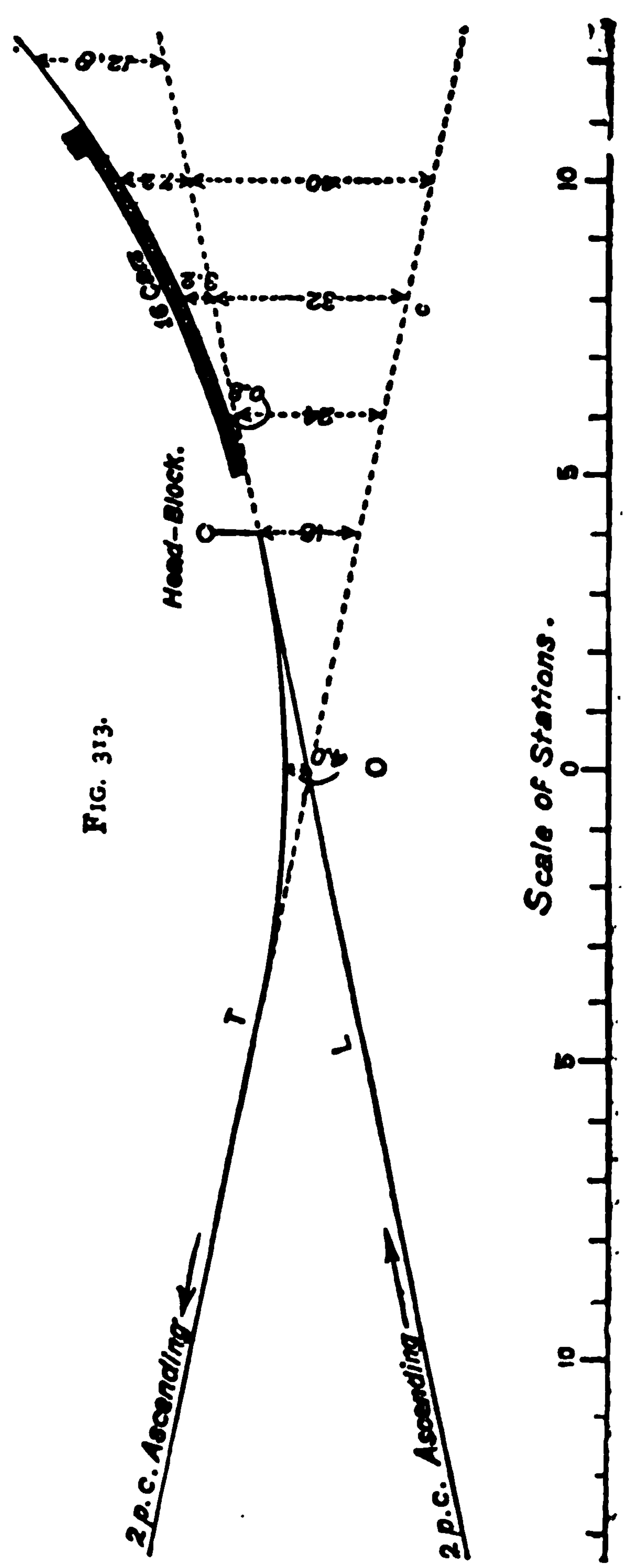

FIG. 313.

As respects the Adjustment of the Grades.—Fig. 313 shows in detail what the writer regards as the proper adjustment of grades for a 2 per cent switchback, and the principle of the adjustment for any grade. With this arrangement it is unnecessary for an up train to use brakes, or even shut off steam at all, for making the stop and then starting backwards.

It will be seen that the up grade continues unbroken until it has passed the switch and then rises in a sharp vertical curve, which rises

above the regular grade, slowly at first, and at the further end—merely as a precaution against accidents—rises very rapidly indeed. This is to bring the train to a stop slowly and gradually, but certainly, without either shutting off steam or using brakes. The rise necessary to do this for any given train speed may be computed exactly, and is given in Table 118 of this volume.

Suppose a train to be ascending the 2 per cent grade at a uniform speed of 15 miles per hour. Then, by the table, a lift of 7.99 ft. above the regular grade will bring it to a stop even with the engine still using steam. If the velocity be only 10 miles per hour, a lift of 3.55 ft. only will be necessary, and this will or can readily be made to be the usual speed of approach. In that case, if the train consist of 10 cars and be 400 ft. long, it will come to rest with the steam still on, unchanged, when the rear of the train has passed a little over 100 ft. past the switch, the centre of gravity of the train being then 3.55 ft. above the tangent grade-line. The slack of the train will be taken out, under these conditions, very gradually indeed, and almost at the instant of coming to rest.

If, then, without changing the throttle, the reverse lever be thrown over into back gear, or even merely into mid-gear, so as to do no work at all, the train will immediately start backward, still holding all the slack out of the train, which will continue out until forward motion is resumed at the next switchback. If the lever were immediately placed in the same notch of back gear in which it formerly stood in forward gear (which would be unnecessary) the speed which the train would have acquired on resuming the upper straight grade at *T*, Fig. 313, would be that due to the height *c*, which is $3.55 + (8 \times 4) = 35.55$ ft., or, as per Table 118, $31\frac{1}{4}$ miles per hour, an objectionably high, but not dangerous, speed. Had the velocity of approach from below been 15 miles, this speed would have been that due to 37.99 ft. or only $32\frac{3}{8}$ miles per hour, and had the velocity of approach (in case of passenger trains) been even 20 or 25 miles, this speed would have been only 36 or 39 miles per hour. Thus the switch, with grades arranged as shown, can be run through at any speed, making no more change in the brakes, steam or engine, than to throw over the reverse lever, at the moment the train comes to a stop, from full gear forward to full gear back.

With ordinarily careful and safe working, the speed at *T*, Fig. 313, would be about 10 miles per hour higher than the speed of approach, a gain far more than sufficient to obviate all loss of time from the stop, and equivalent (for speeds of 10 miles per hour approaching and 20 miles leaving) to a subtraction of 10.65 vertical feet from the rise in the next

grade—a gain which will considerably increase the average speed or hauling capacity, or both.*

Fig. 313 equally well represents the conditions at the next ensuing switchback, where the train approaches rear-end to it, if we simply assume the engine to be at the other end of the train. It reaches the position shown, backing up from below, with all slack out of the train. In starting forward on the up grade, the rear end of the train, being on a steeper grade than the engine, will tend to crowd slightly upon it, and by setting the reverse lever in the second or third notch of forward gear, the slack will be taken out in the gentlest possible way, far more gently than is ever possible in starting on a level.

Thus the ordinary and great objections to sharp hollows in grade-lines do not apply in this case. On the contrary, the action is smoother than it would be without the curved profile. Similarly, the still greater objections to a stop on the grade-line do not apply at all in this case. We rather gain by it, because the whole train stops and starts again with the gentleness and economy of energy of a pendulum, for identical mechanical reasons.

This being so,—there being no loss of time, no loss of distance, no loss of hauling capacity, and no measurable loss in smoothness of motion,—we have left as a net gain two things: *First.* A great additional safeguard against collisions with and derailments of runaway trains or parts of trains. Accidents resembling the terrible one on the Southern Pacific, on the Tehachapi grade, some years ago, in which nearly all of a train-load of people were killed or injured, are not likely to occur. Before a train can attain a velocity of 60 or 70 miles per hour it must fall 128 or 174 feet in excess of the fall required to overcome its resistance. If we estimate its average resistance in acquiring that speed at 20 lbs. per

* If the train were running up a straight grade *LOT* at 15 miles per hour (say 22 feet per second) in $\frac{400}{22} = 18.2$ seconds.

Via the switchback it takes:

O to stop, 800 feet at average speed of about				$\frac{0+22}{3}$	= 48.5	seconds.
Stop to *T*, 1200	"	"	"	" $\frac{0+37}{3}$	= 43.3	"
					91.8	"

Loss of time, as nearly as may be, $1\frac{1}{2}$ minutes.

The train is then moving 10 miles per hour faster, so that it will save this lost time almost within the next mile.

ton, equivalent to the acceleration on a 1 per cent grade, a train must descend a 2 per cent grade for 2½ to 3½ miles before it will acquire those velocities. A single car would take much longer yet, so that a switchback every 3 or 4 miles would go far to insure against the worst results from such catastrophes, which no care can wholly avoid.

Second. A great reduction in cost of construction and amount of curvature, and usually in rate of gradient as well, is assured; in some cases more than others, but always considerable. In the line described in this paper, the writer estimates that half the curvature, and nearly half the cost of construction to sub-grade, might have been saved by using not more than eight or ten switchbacks on the whole ascent of 8000 feet, through the better choice of ground afforded. An entirely different route would have been selected, and nearly the whole line might have been reduced to but little more than a surface line.

On the other hand, there is the unquestionable disadvantage in switchbacks, that engines do not pass curves well running backward. In part this is remediable in the design of engines, and by leaving the rear drivers blind, but the only proper course would be to use an easier maximum curve on the sections on which the engine runs backward, which would be the same both ascending and descending, and to make those sections as short as possible.

Thus, the writer believes, this objection, while it cannot be entirely removed, may be reduced to very small dimensions; and should it again fall to his lot to locate a line of railway upon an ascent of 8000 vertical feet, or even a half or a quarter—or, possibly, even an eighth—of that amount, he will in no case willingly attempt to locate it for an unbroken locomotive run, but either use switchbacks for a light traffic, or study with great care the possibilities of the locality for inclined planes with a heavy traffic.

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INDEX.

References to tabular matter are indicated by *, and references to many of the more important conclusions for immediate application are in SMALL CAPITALS.

To save space, many page references are marked thus:

500 +, meaning "Page 500, and following pages not in the immediate context."

500 −, " "Page 500, and preceding pages not in the immediate context."

500 ±, " "Page 500, and pages both preceding and following not in the immediate context."

500 &, " "Page 500, and in various other places throughout the volume, to which more specific reference under this head did not seem convenient or expedient. See elsewhere."

q.v. (which see) has been used in many cases for giving cross-references, as most economical of space.

Because there are many cross-references it must not be assumed that they always exist.

Bra–Bui

Bul–Car

Car–Car

Car–Cha

Cha–Chi

Chu–Col

Engravings

Engravings

Eng—Eur

Eur—Exp

Imp—Jac

Jal—Lak

Lan—Loc

Loca—Loco

Locomotive

Locomotive

Nec—New

New York

New—Nor

Ris–Rol

Rol–Sax

Sca–Slo

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